A TREATISE

ON THE

MOTIVE POWERS

WHICH PRODUCE

THE CIRCULATION OF THE BLOOD.

BY EMMA WILLARD.

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TO

DR. AMATUS ROBBINS, M.D.,

In token of high consideration for his scientific attainments, and his medical skill, as attested by more than twenty years' successful practice in the Troy Female Seminary—in grateful acknowledgment for his candid and patient attention to the subject of the following pages, and especially as a memorial of high esteem for his moral and Christian virtues,

THIS WORK

IS MOST RESPECTFULLY DEDICATED

BY HIS FRIEND

EMMA WILLARD

Troy, March 3, 1846.

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PREFACE.

If the reader has known what it is to be called on to sacrifice, it may be, the good opinion which he values, in acting for the advantage of those by whom he fears he may be censured, he will then be able to judge of the foreboding apprehensions which at present fill the mind of the writer. My historical works have just been kindly received by my country, but I am concerned lest now it should be said, "she chooses a subject unsuited to her sex."

In answer, I would say, that this is not so much a subject which I choose, as one which chooses me. It comes unbidden to my mind, and like an intrusive guest, there it will abide, and irresistibly claim my attention. But why thus visit me? Whose bidding does thought obey? Under whose control is the world of mind as well as the world of matter? And if the "Father of Lights" has been pleased to reveal to me a sentence before unread from the book of his physical truth, is it for me to suppose that it is for my individual benefit, or is it for you, my reader, to turn away your ears from hearing this truth, and charge its Great Author with having ill chosen his instrument to communicate it?

Sons and daughters of the Puritans! your fathers set the

world an example of independence of mind and conscience in matters relating to the soul. They claimed the right of studying and judging for themselves in that which concerned their spiritual life and health. Suppose that you, their descendants, should go one step further, and take the same course in regard to those things which concern the body; considering that the same Being who is the "Father of your Spirits" is also the "Former of your Bodies," and that you are responsible to him in both cases for the manner in which you treat his workmanship. And although in the one case you have great confidence in your minister, and in the other in your physician, yet, if your minister teaches you unsound doctrine, and you believe and act upon it, the forfeit will be yours, because you should not blindly follow man; so in the other case, if the physician gives you deleterious drugs, although he may be wrong, you have to bear in your own body the consequences of that wrong; and if you have failed to inform yourself of the great laws of your physical nature, you are blameworthy as well as unfortunate.

In this little book I have avoided learned words and phrases, even where I understood them; and have used such illustrations as I hope will be plain and interesting to all. In respect to the knowledge and skill of the medical profession, I rate it highly; for I know how much it has cost me to follow out this one track, and I see how great the whole field is. But at the same time I should object to a jury wholly made up of the medical faculty to judge on the theory here proposed. Their pride of opinion may naturally be wounded, and unconsciously to themselves, they may let "self shake the wavering balance" in which truth should be impartially weighed.

INTRODUCTION.

The Theory which is the subject of the following pages, occurred to the mind of the writer in the summer of 1832, during the ravages of the Asiatic cholera. It was suggested by some of the symptoms of that dreadful malady, to a mind previously convinced, to use the words of one of our most eminent physiologists, that, "whatever is the principal cause of the circulation, the heart's action is not." So many proofs occurred of the truth of the hypothesis about to be presented to the reader, that its outlines were committed to writing at the time; and to a scientific friend, Professor Twiss, now of Columbia College, S. C., was assigned, by his consent, the task of entering the field of investigation which it opened, and, unless some fallacy was detected, to give the theory to the public, in case of the author's death; a contingency which, at the time, was naturally present to the mind.

Subsequently, I employed professors of chemistry for two winters to assist me in several experiments

connected with the subject; and in 1835, having been able to answer to my satisfaction the objections which had occurred to my own mind, or had been suggested by others, I wrote out the theory and sent it, anonymously, to Professor Silliman, for publication in the "Journal of Science." Its progress then was stopped by the remonstrance of an elderly medical gentleman, to whose inspection it was very properly consigned. This excellent and learned man sent the manuscript back with a letter of objection to the theory, founded mostly on suppositions then afloat, but now sunk to oblivion.

In the autumn of 1839, I again turned my attention to the investigation of this theory, having in the meantime been a close observer of whatever phenomena, both of physiology and pathology, connected with it fell under my notice; and having also had the views of a number of medical gentlemen, to whom I communicated my own. One of these, Dr. C. Smith, a skilful dissector, showed me the actual structure of the organs of respiration and of circulation; employing the scalpel on the hearts, lungs, &c., of animals which were not slaughtered for the purpose, but procured from the butcher's stall. By this gentleman's persuasion the author also witnessed the post-mortem examination of the thorax of a child, by

which a disputed point was settled in favor of the theory herein advocated; and finally, the result of the author's investigations was a firmer conviction than before of its truth and its importance. But shrinking from the task of publicly advocating what might expose me to attacks against which perhaps, I could not to defend myself, without the sacrifice of feminine propriety, I resolved rather to re-write my theory, and send it in manuscript to some among the most eminent physiologists abroad, believing, that if their sanction was obtained, I should be relieved from the evils which I apprehended, should I publish it in my own name at home. Dr. Smith remonstrated in the following language which I quote from a letter written in December, 1839. Results have shown, that his views of the futility of sending the theory abroad for foreign sanction were fully correct:

"MRS. WILLARD:

* * * * *

"You stated that you intended to send a document to Paris and London, which I do not hesitate to say will avail you nothing; and, in view of your theory, I take the liberty to say, that you have thrown much *light* upon the theory of Respiration and Circulation, which can, and ought to be made to radiate in our

own country, which, if you send abroad, not a single ray will fall upon our own land.

"I take pleasure in acknowledging that the following considerations are derived from your suggestions.

"The new, ingenious, and important discovery of the increase of volume of blood by the addition of caloric, is without doubt the 'Primum Mobile' of the Heart's action, because the blood is continually flowing into the left auricle. Hence it is even made (the auricle) to empty itself into the left ventricle, thus stimulating it (the ventricle) to *contract.* The blood is not propelled by the auricle into the ventricle, but enters the ventricle whenever there is a vacuum. Allow me to assert that there is not a muscular fibre in either auricle, and in my opinion (from recent dissections), the auricles are nothing more than reservoirs. (Signed) C. Smith."

Yet, notwithstanding Dr. Smith's remonstrance, the plan mentioned was pursued, and the treatise was for this purpose written, which constitutes the first chapter of this work. Copies were sent to the brothers, Drs. Milne and William Frederic Edwards, of Paris, and to Dr. Abercrombie in Edinburgh. Dr. Abercrombie complimented the writer, but did not

give his opinion of the theory. Dr. Milne Edwards deigned no reply,—but he has projected a theory of animal heat, which would subvert what, both before and at the time I wrote, was regarded in this country and in England as fully established; and which lies at the foundation of this theory. From Dr. William Frederic Edwards, since deceased, I received in 1841 a letter with objections to my theory, which will be noticed in the following pages.

The years succeeding 1839 were so wholly absorbed in the revision of my works on History, that I had no time to devote to any other study. But the house of clay in which the mind dwells, must receive a portion of its care; and that which I have bestowed has proceeded on a belief in the truth of the theory herein advocated, as undoubting as is my belief in the laws of gravitation; and when any new fact or any remark of an author relating to my theory came under my observation, I noted it down and laid it by with its kindred. About to set out on a long journey, and aware that my field of vision had thus enlarged, I felt it my duty to put together the principal of my remarks, that I might so leave the subject, that in case anything should prevent my return, it would be in a form equal to the present state in which the theory exists in my own mind.

On again sitting down to the subject, its importance in regard to human life struck my mind with new force; and the objections which had arisen from the French theory, seemed to me almost to militate against the honor of God, since they go to show that respiration is of little use. Conscience moved, and I said, "The Great God has so done his marvellous works that they ought to be had in remembrance." To serve him by doing good to men, should be the chief aim of existence, and He will ultimately bless the effort. If the neglect or contumely of men should for a time be its consequence, let the future be regarded. The rod with which man scourges his fellow, who tells him important truth for his good, takes root in after-times, and blossoms on the grave, —when the enshrouded form no longer confines the spirit.

CHAPTER I.

THE THEORY OF A MOTIVE POWER BY RESPIRATION, ANIMAL HEAT, AND EXPANSION.

As written by the Author Dec., 1839.

SECTION I.—EXPANSION A MOTIVE POWER.

THE object of the following Sections* is to show that Respiration, operating by Animal Heat, produces an expansive Power at the Lungs; and thus becomes the principal efficient cause of the blood's circulation.

1. *The Blood receives Caloric at the Lungs.*—A chemical combination of oxygen and nitrogen is inspired. A part of the oxygen is detained,† and in

* This and the following Sections contain the theory of a motive power by expansion, as made out by the author, December, 1839, and circulated in manuscript, it being the same statement which was sent to the Drs. Edwards, in Paris, and the same which is alluded to in the letters of Dr. Marcy and others (See Appendix, No. I.). Several copies of it are now extant in manuscript in this country, and some in Scotland and in France. Additional remarks or explanations will be introduced in brackets or in notes.

† The oxygen returned in combination with the carbon in expi-

its place carbonic acid gas and watery vapor are expired. Hence caloric must have been evolved, and, from its nature, have passed the thin separating membrane, and infused itself through the blood in the lungs. This we regard as already demonstrated [i. e., by chemical writers, as well as by the plain chemical phenomena, and the fact known to all, unlearned as well as learned, that the heat of the body originates at the vitals, and is lost at the surface].

2. *The Blood must therefore Expand.*—The expansion of fluids by caloric is a doctrine so perfectly understood and established, that it needs no comment, but it is important to our purpose to consider, that, in this case, *there must be a very considerable expansion.* Notwithstanding the great quantity of caloric

ration is found to be the same in amount as that inspired in combination with nitrogen, i. e., in the atmospheric air. And on no law of chemical affinity can the conclusion be avoided, that there have been chemical decompositions and recompositions, by which caloric must have been evolved. The lungs are *at least as much heated* as any part of the body, and if oxygen and carbon would chemically combine anywhere in the system, they would here, and facts show that they do. We quote the following passages from Liebig's "Animal Chemistry," a work with which we do not, however, always agree:

"In contradistinction to this phenomenon of vitality in plants,

carried off at the surface, enough is received to keep up a mean temperature of 98° Fahrenheit. The temperature of venous blood is stated by Magendie to vary from 101° to 75°,—that of arterial blood to be nearly 104°. Taking 88° as the mean temperature of venous blood, we have a difference of 16° which the vital action at the lungs upon the air there received is to supply. [Later reflection has shown me that the whole difference between the extreme heat at the vitals, and the coolness at the extremities, is available in carrying on the circulation. (See Appendix, No. II.) And the consideration that the force works in vacuo, is highly important in showing its efficiency. In air, 212° is the point at which a fluid boils; 72° the point at which it boils in vacuo, which is 6° below mean temperature; 32° below that of arterial blood.]

The quantity of blood in the lungs has been stated by physiologists at $\frac{1}{5}$ of the whole—five pounds out of twenty-five.* This receives caloric, not like water

we know that the animal system absorbs oxygen from the atmosphere, and that this oxygen is again given out in combination with carbon or hydrogen; we know, that in the formation of carbonic acid and water, the heat necessary to sustain the constant temperature of the body is produced, and that a process of oxidation is the only source of animal heat."

* The statements of other writers make the quantity of blood at the lungs $\frac{1}{7}$ of the whole, which they reckon at thirty-five pounds

in a vessel over a fire, at one small surface only; but over a space, which has been variously estimated, but by all acknowledged to be great. Making a computation on Dr. Keill's statement, the blood at the lungs receives caloric over a surface equal to the area of a circle whose diameter is nearly seventeen feet, so that if the portion received at each particular point should be small, *the aggregate must be considerable.*

3. *If the Blood expands it must move.*—This is perfectly evident, for to expand is to spring into a larger bulk, and the space which has contained the blood can contain it no longer; so that *this expansion must be a motive power.*

4. *If the Blood moves from the Lungs, it must move towards the left ventricle of the heart, and from thence into the aorta, and so on through the arteries.*—For it must, *of the two directions, take that in which it can move,* and not that in which it cannot. Here arise important considerations respecting the animal struc-

instead of twenty-five. Both the quantity and proportion vary in different subjects. So also do the dimensions of the aorta. Where the aorta is an inch in diameter, I believe there are more than five pounds of blood in the lungs, probably seven or eight.

ture, as a machine made for receiving streams of a fluid, moved by the same agent which warms it; for it is not a power, like impulse, indifferent to direction. It is the antagonist principle to gravitation, and its natural tendency is upwards.* When particles of fluid become more heated than others with which they are connected, the heavier fall downwards, and force upwards the lighter. This, in the consideration of the whole subject, must be regarded, as well as *the absolute power produced by expansion;* a power which, in its high and explosive state, is the most tremendously destructive of any known to man: yet, as in the present case, where a fluid passes merely from warm to warmer, it is the most kindly and gentle force that can be imagined—yet if we consider that it is generated in the lungs over a space equal to a circle whose area is about seventeen feet diameter, and concentrated in a tube (the aorta) of one inch diameter, we shall no longer be astonished at the force of the current found there. Suppose one should, on a mild spring day, place a lens of the diameter of seventeen feet, so that it would receive the rays of the sun, its focus being in diameter one

* We must not, however, lose sight of that law of caloric which regards its radiation in all possible directions, by which it is transmitted to adjoining substances till they are in equilibrio.

inch—would not its force be intense? or suppose (a case in which the laws of hydraulics are regarded, and which will on that account be more directly in point) a machine constructed like a syringe, with a piston of five yards in diameter, and a spout of one inch bore—how very slight must be the movement of such a piston to send a fluid from the spout with the velocity of the blood in the aorta.

SECTION II.—THE HEART'S ACTION.

We have proceeded thus far, without paying any attention to the former theory, which makes the motive power, a mechanical force generated by the beat of the heart, and synonymous with pulsation, for,

First, we *show by a positive argument that a power is generated in the lungs by respiration ;* and, second, that *there is good reason to believe* that this power, when the system is in a healthy state and in its natural (i. e., in an upright) position, is *sufficient to account for the force of the current found in the aorta* and its branches ; and, as *all calculations of the power of the heart* and its *contractions* have *been made by estimating the force of that current*, therefore, if the

chemical theory just advanced be allowed, the former mechanical one must, at least in part, be abolished.

But it may be argued that the blood flows in pulses, and those we know are originated by the beat of the heart, and therefore the motive power must reside in the heart. To show the futility of such an argument, suppose an india rubber tube of any length, not very great, as six feet, be filled with water, and placed in a coil upon a table; there would in this case be no current; but strike successively upon one end of the tube, while you place your finger upon the other, and you will feel a pulsation seemingly simultaneous with the stroke. Again: take the same tube, and attach it to the orifice of a vessel filled with water which you wish to empty. Lay it along an inclined plane, and the water will flow through it in an equable current, more or less rapid, as the plane upon which it lies is more or less inclined,—the force by which the fluid moves being that of gravitation. We here see, that pulsation and *that motive power* which produces a current, are entirely different, and exist separately. They may also exist in combination. For let the india rubber tube, which is carrying the current of fluid, be grasped by the hand near the orifice of the vessel, in successive contractions of the fingers, a corresponding pulsation will be felt all along its

course, and the water will pass on through it "per saltum," like the blood in the aorta; and will issue from it in leaps. Yet in this case, if no valves are in the tubes, the successive contractions of the hand driving just as much of the fluid back as forward will add nothing to the motive power, which produces and keeps up the current.

But suppose there had been valves placed along the tube, closing towards the orifice, then a contraction of the fingers upon the tube would have aided the motive power by adding, in a degree more or less slight, the force of impulse to that of gravitation. We conceive it to be a fact concerning the human system, that the contractions of the heart aid in a similar manner the motive power which, after respiration begins, gives the first movement to the current of animal life, and without which it must cease.

We do not, however, limit the office of that noble organ, the heart, to the adding of a little more moving force to the vital current, but consider *that it furnishes the grand machinery by which the gates are hoisted that allow the tide of life to pass to its destination through its appointed channels.* Its valvular system, opening and shutting in such a manner that the same strokes which allow the expanded fluid to pass to the aorta, open the way for the partial va-

cuum to be filled in the lungs by the colder and denser blood coming on from the right side of the heart to be warmed and expanded in its turn. And by its mechanical power the same strokes which do this, at the same moment give a quicker impulse to that vital current, which, with regard to the lungs, is outward-bound to nourish the system, and that stream which is inward-bound to be revivified.

This view of the functions of the heart perfectly vindicates the Divine Wisdom in its formation. Had it been intended for what the former theory supposed, it would not have been left to play so loosely in the thorax. But if it is to receive the first gush of life, as it rushes from the fountain, *where it is put in motion, by a power varying with circumstances*, it should swing loosely, that its moorings be not endangered. It should be safely guarded against bursting. The grand office to be performed by its beat, the opening and shutting of the valves, is not hindered by the change of place incident to its unfixed position.

Again: we believe concerning the heart (and the fact we have derived from observation), that when the posture of the body is unfavorable to the action of the chemical force produced in the lungs, that then the heart labors with additional force to keep

up the circulation, and that to a certain extent this labor will be in proportion to the failure of the chemical power.

The expansive force will, we suppose, operate best when the trunk is upright. Indeed, we have reason to believe from the evidence of facts that this position being kept, circulation and warmth would continue, if the lungs were healthy, should the heart cease to beat, or should its valves become ossified; while a recumbent posture, under the circumstances, would cause instant death. But in ordinary cases, if the body becomes recumbent, the heart takes up a stronger beat, which continues until the current has received its momentum in the new direction. This any one may observe as he lies down to rest when in health. But when disease or hardship has impaired the vital powers of the lungs, then the heart labors night and day, and while it is making efforts to relieve the lungs it is said the heart is diseased, and when, in consequence of this preternatural labor, its size and strength and power are increased, that the disease is (not the loss of vital power in the lungs) but an enlargement of the heart.*

* Actual enlargement of the heart is produced most commonly in this manner, and *real disease*, in which the heart by over exer-

SECTION III.—THE VENOUS CIRCULATION, EXPERIMENTS, ETC.

It has been asked whether the chemical theory of the motive powers affords anything to solve the problem of the circulation through the venous system and capillaries. The answer is affirmative. In testing the correctness of this theory, which asserts that a circulation may be kept up by applying caloric to one part of the circulating system, several experiments have been performed which would have detected us, had our reasoning been fallacious. The figure No. I. first was made by means of the simple apparatus represented in figure No. I. This was formed by joining two glass tubes B B by india-rubber, I I, then filling the apparatus with water, and exposing the part indicated by the position of the candle to the action of its heat, particles of the water received caloric, expanded and ascended, and *let it be remarked* as essential to the point now in question,

tion loses its vital power. Its size increases, and its texture is sometimes found, on post-mortem examination, so far decomposed that a finger may be thrust through its sides as easily as through a mass of wet paper. In these cases the patient before death is constantly kept up at night; and he dies instantaneously on declining from that position. (See Chapter II.)

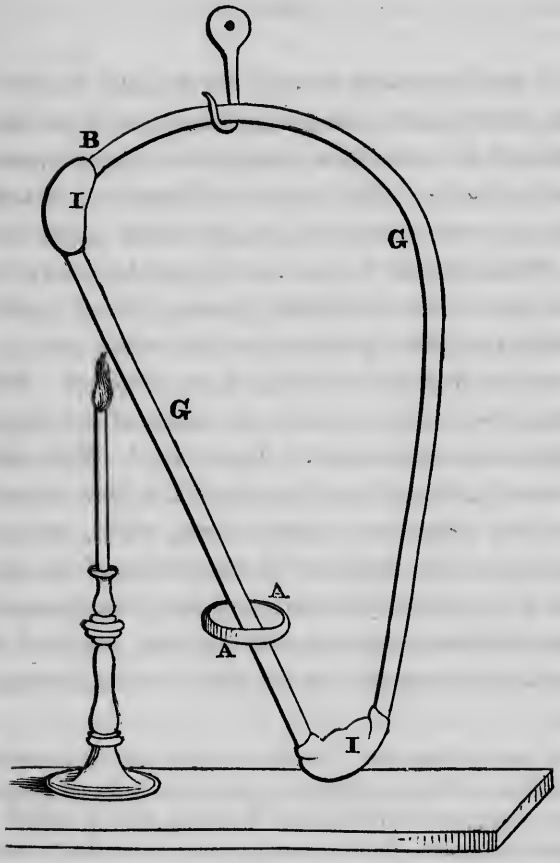


Fig. No. I.

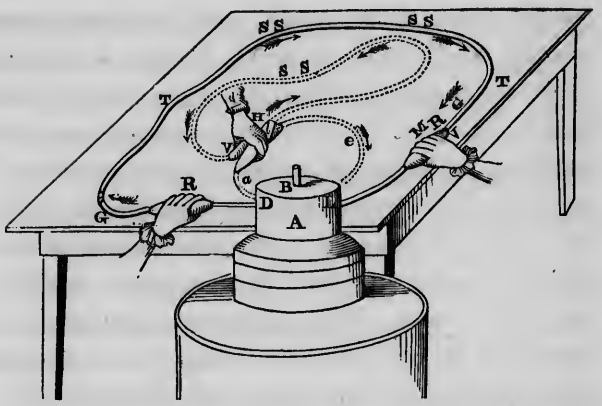
*the lower and colder particles rose to supply their place,** and thus the caloric at the point of its application had an effect on the fluid beneath, as well as on that above; and the remainder, easily displaced by their double influence, being driven by that which was sent upward and drawn constantly on to supply the place of that which was thus raised, a circulation was produced, which would go on while the fluid was heated as it came to the proper point, and cooled as it wore off; provided the upright position of the machine was maintained.

[Subsequent study and reflection have extended my views on this part of the circulation. What is stated here is doubtless truth, but it is not *all the truth.* The radiation of caloric from the lungs would cause all the organs of the body to become of equal heat with the lungs, until they approached so near the surface that there would be a tendency to equilibrium with the surface of the body, where heat is carried off both by evaporation (as perspiration in health is constant) and by radiation to the garments worn, and to the surrounding air. So that when

* This suction power would apply equally to displacement of the fluid by the heart's impulse, were it not for the nature of the conductors, whose elastic or collapsing texture affect very differently the mechanical and chemical forces.

capillary attraction has conducted the blood from the arteries to the veins, and is crowding it forwards to make room for that which is constantly coming from the arteries, it then being at its minimum temperature, it begins to become more heated as it ascends by the surrounding solids, and as it rises into the internal parts of the body, the ratio in which it will receive caloric will increase, and it will thus receive an upward impulse, quickening in a geometric ratio as it approaches the lungs, and after its temperature is 72° it will, as it works in vacuo, have passed the point when the watery particles of the blood will spring into vapor.]

But it may naturally be asked, since the experiment related shows the effect of expansion only when the fluid is permitted by the tube to rise immediately after leaving the heated point, would the same effect occur in a different position of the apparatus? Not only to satisfy this query, but other important ones, we describe the following experiment, made in 1835. To a vessel of tin, A (see next page), holding three pints (and having on the top a short tube, B, through which the apparatus was filled with water) was attached a tube, I I, mostly of lead, about six feet in length, and one inch bore. A valve, L, was placed at the entrance of the tube into the vessel opening inwards. Near the vessel and on each side were



pieces of india-rubber, R R, and on the sides of these, opposite the vessel, short glass tubes, G G, for the purpose of observation. The india-rubber on the right of the vessel where the hand was to be clasped, had on each side valves O V, opening towards the tin vessel. This apparatus was filled, and the tube laid horizontally upon a table, on a level with the orifices in the tube, with which it communicated. The vessel was then placed over the blaze of a portable furnace. The fluid as it expanded passed out at the left side of the vessel; but the same expansion pressing the water upon the valve L, on the right, kept it closed, so that no circulation could take place. Then the hand was applied to the india-rubber at M, and as the fingers contracted, the valves O L opened

and the water glided quickly into the vessel; then relaxing the fingers, the valve V opened, and the water from without filled the space between the valves; and thus by alternate contractions and relaxations [so gentle as merely to open the valves] the whole fluid contained in the apparatus was put into rapid circulation, and the extreme part of the leaden tube soon became of a temperature equal to that of the vessel. This experiment shows the necessity, on the supposition of an expansive power, of an organ exterior to the lungs, whose play shall open and shut the passages. And how beautifully is the heart adapted to this purpose! As independent of the lungs as the musician of his instrument, yet even as we breathe, whether quicker or slower, the heart beats, not in unison, but in harmony.

[A circumstance attended this experiment which was of much significance to our theory. When the fluid in the part of the tube opposite and farthest from the vessel became of nearly equal heat with that in the vessel, the circulation became languid, and when equal, of no force whatever. Snow was applied to the part of the tube S S most distant from the tin vessel. This immediately quickened the circulation, and thus we proved by experiment that the circulation in such a case is of a velocity proportional

to the whole difference of temperature between the extremes, i. e., the maximum heat of the fluid at A, where the caloric is generated, and the minimum at S S, where it is lost.]

Applying the principle to the venous circulation, we perceive that the expansive force not only sends out the blood from the lungs, but also that this outward movement would produce, to fill the partial vacuum, an inward movement from the opposite direction.

As it regards the capillaries of the system, this theory adds something to those heretofore received, and doubtless correct. For it is true there must be a *drawing power* to lead the fluid onward and upward towards the heart and lungs, as well as a *driving one* to the capillaries coming from these organs. As to the blood in the capillaries, it is needful that it expand over a vast surface. It is meet, therefore, that it should be checked in its current. It is a river which, being dammed up, spreads broad and far, and gives life and beauty. As we look upon the expanded surface we do not doubt, although the waters appear stagnant, that they are living, and creeping along in a current through the sedge which seems to bar their way, for they are supplied by a stream which does not set back, but keeps up these waters to their height,

notwithstanding exhalations from a broad surface; and after passing their expanse they again resume their flow.

The *effects* of *muscular exertion* in quickening the current of venous blood, ought to be taken into consideration; and also the momentum of the fluid, when once put in motion, and with these we see not but the circle of powers is complete, which together sustain the motion of the vital current.* The first and most important of these we believe to be generated at the lungs; for as soon as the animal becomes a being of air this must operate, or circulation is not produced. The phenomena occurring at birth proves this. If the infant does not breathe, the blood does not circulate; if it breathes, it does. In cases of suspended animation, artificial respiration, and that alone, may set the vital current in motion. "When we open the thorax of a living dog" (says John Bell), "the lungs collapse, the heart soon ceases to play, the dog languishes, expires; *is revived again when we blow up its lungs;* then begins again the motion

* The effect of caloric transmitted to the solid parts of the body, and expanding by increase of heat, the upward current of venous blood should be taken into the account. It will also appear in the second chapter, that the expansive power may make gravitation itself subserve the purpose of circulation.

of the heart, the black blood of the right auricle is driven into the lungs; the blood goes round to the left side of the heart, of a florid red; and the purple blood of the veins, the vermilion blood of the arteries; THE CHANGE HAPPENING SO PLAINLY FROM ACCESS OF AIR, is a phenomenon of the most interesting nature, *and bids us look into the doctrine of* CHEMISTRY for the solution of a phenomenon TO WHICH THERE IS IN ALL THE ANIMAL ECONOMY NOTHING EQUAL."

Doubtless, there must be a connection between the play of the lungs and that of the heart, as the former invariably precedes the latter. That connection must be caused by the fluid, which, as life first springs within the vital circle, proceeds *not from the heart to the lungs, but from the lungs to the heart.* If, then, the first and second inspirations give the blood an impulse, which sends it to the heart, what should hinder the third and fourth from doing the same, and so on, while respiration continues? Not, surely, the beat of the heart, for that would have no more effect to destroy the force produced in the lungs than in the former supposed case of an india-rubber tube, used in emptying a vessel; the successive contraction of the fingers upon the tube would destroy the power of gravitation, by which the current is produced and kept up. Those contractions may modify

and may accelerate, but cannot destroy the power, or, without danger, obstruct its operation.

Before dismissing this part of the subject, let us observe how the grand law of hydraulics, that the momenta of moving fluids are equal, may affect the phenomena of the circulation of the blood; of the whole circulatory system the aorta has the least capacity, and consequently the blood then must have the greatest velocity.* Branching out in every direction, the arterial capacity increases, and of course its velocity diminishes. At the capillaries, the aggregate capacity of the innumerable containing tubes becomes very great, and of course the velocity is proportionally small. The veins, as they unite in their passage to the heart, are considerably more capacious than the arteries at the same distance from that organ. But it is material to the present argu-

* So say the writers, and in general terms, speaking of the whole current, this may be sufficiently correct. But I have not the least doubt, that the velocity in the arteries leading to the head is many times greater than that in the aorta while the head is erect; and as the carotids are more exposed to observation than the aorta, the current in the aorta has been measured by that of the carotids. But the expansive theory would lead us to believe that the best heated blood would be constantly ascending, and that quickly, to the head, while that in the lower part of the aorta, as its crown, would be more slowly making the downward turn.

ment to remark, that the capacity diminishes as it approaches the heart and lungs, probably quite* as much as the arterial increases in going from them. This fact proves that the velocity of the venous blood is greatest as it approaches these organs, and consequently, that the blood in their neighborhood is drawn towards them, by the suction power already described.

SECTION IV.—PROOFS OF THE THEORY FROM THE ANIMAL STRUCTURE. RESPIRATION THE INVARIABLE ANTECEDENT OF CIRCULATION.

WHOEVER looks in earnest for anything where it is, will not fail to find it. Hence, we feel certain that the enlightened and unprejudiced anatomist, who shall look to the animal frame for proof that it was

* The contraction of the channel through which a current of fluid passes, of necessity quickens its velocity. But if the motive power were not increased proportionally, the containing tubes would be subjected to a dangerous pressure. Dr. Arnott asserts that no suction power, of any avail, can be originated by the heart's action, on account of the yielding nature of the conductors of venous blood. This reasoning does not apply to a suction power produced by expansion; but, as before remarked, the expansion created by the caloric of the inner regions, transmitted to the blood in its upward course (which had not occurred to me when this

made in reference to the motive power here supposed, will not fail to find it. Why is it, that when *one long tube, unvarying in diameter*, carries the blood from the heart towards the lungs, that it is sent from the lungs to the heart, *in four tubes, short and rapidly increasing?* Why, but because there is less danger of bursting in the former, than in the latter case. To the same cause may be referred the great difference observable in the parietes of the right and left ventricle of the heart. The left ventricle has stronger walls, because there is more danger of their giving way, from the greater force of the current received.

Look at the beautiful up-springing of the carotids from the crown of the aorta. The revivified blood finds but a short course from the lungs to their entrance. Yet had any particles been left more cold and heavy than the rest, they have had an opportunity in turning the point about the mitral valve to drop into the chamber of the left ventricle, or being crowded out, they would not rise to the *top of the aorta*, which alone sends out the blood through those

statement was made), should be added to the account of the powers which produce the venous circulation, and it should be considered that in vacuo the boiling point of water, and probably blood, that containing so much water, is 72°.

arteries, so that the most heated and expanded of all which passes from the heart, mounts to the brain; nor is it forced on an unwilling course by a mechanical power, but it springs gladly upwards, and lest it should set with too much velocity upon the delicate fibres, the Creator has checked its flow, by making for it a sinuous course through bone.

Nor is this winding pathway of the inner carotids the only or the most striking proof of the chemical theory, which the bones afford. How admirably is the whole osseous structure of the trunk formed for respiration! Observe what an array of muscles also are contributing to this grand effect. Not only can we trace a reference to it in those which raise and depress the ribs and the diaphragm, and at the same time send forward the venous blood, but throughout the body their peculiar function of activity in obedience to the will, is connected with respiration. By their swell they press the black blood onwards into the lungs, giving them the proper stimulus, and setting them in quicker motion. And what succeeds? not more warmth only, but invariably more rapid circulation. The element in which God has placed us is made in reference to respiration, and we know it to be the condition of our being, that we *breathe*, of our *well being*, that we breathe pure atmospheric

air ; and with a movement, too, of the lungs during a portion of the time quickened by muscular exertion.

" Truth and good," says the philosophic Akenside, " are one," and the theory proposed, bears this stamp of truth that it is good. For as to our conduct in reference to health, it sets us upon that course which wisdom has long since known to be the true one. It is also comfortable and satisfying to the mind. We no longer regard our blood as a heavy mass to be lifted upward by a power foreign to itself, and which our senses teach us is insufficient to the task, but we perceive that each atom, endued with comparative levity, might say with Milton's spirits,—

> " But in our proper motion we ascend,
> Descent and fall to us is adverse."

We are no longer inclined to say with the great anatomist, John Bell, *that " it is awful to think of the unfixed position of the heart,"* or are half tempted to arraign the Creator's wisdom, and exclaim with Dr. Arnott, " the heart alone is the rugged anomaly, the signal deviation from the ascertained laws of fitness in mechanics." And with our own heart overburthened and struggling, like Atlas moving up a hill with the weight of existence upon his shoulders, we no longer feel that we must labor in sympathy, but

be all delighted at the thought that the toil is resolved into the process of respiration, which is proverbially easy; and which, having once put the vital current in motion, the gentle beat of the heart sends it leaping joyously upwards.

We perceive, therefore, according to the chemical theory, the chief motive power is found precisely where it should be. To breathe is to live, to stop breathing is to die. *In the first case the blood invariably circulates;* in the last, *its circulation invariably ceases.* The blood of every animal existing in air, begins its course from the capillaries of the lungs and there finds its last retreat. If the breath is interrupted, nature shrinks with involuntary shuddering. Says Paxton, "If the breathing is suspended for many seconds, there is anxiety and fear, and as it were, an instinctive warning of the importance of respiration."

In the connection of the mind with the material frame, we find proof of the correctness of our theory. Why is it that in a state of health, when fatigued with the cares of the day, as soon as I lay my head upon my pillow, my mind becomes inactive and I fall asleep? The head, before heated with over-exercise of the brain, now becomes cool, and the feet grow warm. Doubtless the motive power produced by respiration no longer finds its upward way to the

head, and the brain hence loses its excitement. The pipes of the circulatory system are now laid like a horizontal apparatus, and the blood circulates equally to every part. Examine with Sir Charles Bell the doctrine of the nervous system. See what an array of nerves are provided for the purposes of respiration; and these are bound up by the same vital chord with those of volition and sensation. What can more plainly indicate that respiration is the primary function of animal existence, and that this theory no more than exalts it to its proper place? At creation, God himself lighted its primeval fires; then he formed man of the dust of the earth, and breathed into his nostrils the BREATH OF LIFE, and man became a living soul.

EXPLANATION OF FIGURE ON PAGE 15.

This contains a representation made to aid the memory of the circulatory system with lungs and a double heart. Take the under dotted figure and observe that it is connected with the vessel A (representing the lungs), which contains an expanding fluid, with which the tube is filled. Then, as the dotted tube leaves the vessel at D, an arrow shows a current in that direction; then we perceive a widening in the tube where a piece of india-rubber is inserted, and that this passes under a muscular hand (H), which, at the same time, clasps the similar india-rubber of the returning tube, which after a circuit (e) enters the vessel (A). By the hand (H) closing on the left ventricle (*l*) and the right ventricle (*r*), we represent the double heart, with its power of contraction and distillation, which the motions of the fingers may imitate. By the extreme part of the tube S S (where, in our experiment, we placed snow) we represent the capillaries.

Let the reader now examine the annexed extract from Bichat, and this figure will aid him in tracing (as there described) "the course of the blood." The smaller and larger circulation each going from, and returning to, the heart, are easily traced, as the small takes the lungs in its course, and the large the capillaries. But this division is not (and so say Bichat and Dr. Roget) the most simple and the most natural; but the division is the best which begins (as we believe, with the first spring of the principal motive power) in the capillaries of the lungs, and carries bright red or arterial blood through the left side of the heart to the capillaries of the system, and there changing to dark red, it carries this through the right side of the heart to the lungs again.

In order to get a more clear idea of this, let us suppose the hand (H) unclasped and removed, and the tube no longer crossed in the form of a figure 8, but laid on the table in the manner of the outer tube. You now have the left side of the heart opposite your left hand, and the right side opposite your right hand, the left side carrying red and the right side carrying dark blood. The operation of dividing the heart and putting on one side of the lungs the blood-vessels, which carry red blood, and on the other, those which carry black blood, can easily be made by dissecting any double heart at the septum.* Then you may clearly see that the natural division is into the system of red blood, and the system of black blood; that the lungs are the true centre of the whole system, and that the heart is an appendage of the lungs.

ARRANGEMENT OF THE BLOOD-VESSELS.

Extract from Bichat's General Anatomy, applied to Physiology and Medicine, volume one.—"All authors have considered the circulation in the same way, since the celebrated discovery by Harvey. They have divided this function into two; one has been called the great circulation, the other, the small or pulmonary. The heart being between the two, is their common centre. But in presenting, in this point of view, the course of the blood, it is difficult, at first sight, to perceive the general object of its course in our organs. The method in which I explain, in my lectures, this important phenomena of the living economy, appears to me infinitely better calculated to give a great idea of it.

"I divide the circulation also into two; one carries the blood from the lungs to all the parts; the other brings it from all parts to the lungs. The first is the circulation of red blood, the second that of black.

"The circulation of the red blood commences in the capillary system of the lungs, where the blood acquires, by the mixture of

* The septum divides the heart into a right or an anterior, and a posterior, or left half. The right part of the heart is called the pulmonary heart, or the heart of the black blood, from the color of this fluid within it; the left is termed the aortal heart, because the aorta arises from it, or the heat of red blood, from the color of the blood within it. (See "Manual of Anatomy," by J. P. Mekel.)

the principles that it draws from the air, the peculiar character that distinguishes it from the black blood. From this system it passes into the first divisions, then into the trunks of the pulmonary veins; these force it into the left auricle of the heart, which transmits it to the ventricles and this drives it into the arterial system; this spreads it into the general capillary system, which may be truly considered as the termination of its course; the red blood is then constantly carried from the capillary system of the lungs to the general capillary system. The cavities that contain it are all lined with a continuous membrane; this membrane, spread upon the pulmonary veins, upon the left cavities of the heart, and upon the whole arterial system, may be considered as a general and continuous canal, the exterior of which is strengthened in the pulmonary veins, by a loose membrane, in the heart, by a fleshy surface, which is delicate in the auricle, thick in the ventricle, and in the arterial system by a fibrous layer of a peculiar nature. In these varieties of the organs that are thus added to it without, this membrane remains everywhere nearly the same, as we shall see

"The circulation of the black blood is performed in a manner the reverse of the preceding. It begins in the general capillary system; it is in this system that its blood takes the peculiar character that distinguishes it from the preceding; it is here that it is formed, by the subtraction, probably, of the principles of the air that it acquired by terminating its course in the lungs. From this general capillary system, it enters the veins which transmit it to the right cavities of the heart, which send it by the pulmonary artery to the capillary system of the lungs. *This system is its real termination, as it is the commencement of the circulation of the red blood.* A general membrane, everywhere continued, lines the whole course of the black blood, and forms for it also a general and continuous canal, in which it is constantly carried from all parts to the interior of the lungs. At the exterior of this great canal, nature has placed a loose membrane in the veins, fleshy fibres in the heart, and a peculiar fibrous texture in the pulmonary artery; but like the preceding canal, it remains always nearly uniform, notwithstanding this difference of organs to which it is united externally. It is by the folds of this membrane in the veins, that the valves are formed."

CHAPTER II.

THE THEORY OF MOTIVE POWER BY EXPANSION, RE-STATED WITH ADDITIONS.

SECTION I.

I NOW suppose myself placed in conversation with my reader, who has for the first time been called on to relinquish opinions long held as true, and to adopt others which are yet strange to his mind, and although he acknowledges their reasonableness, yet I fancy him to say, "I must think this matter over." To aid such an inquirer, we shall state the subject again in a different form, bringing forward added proofs, and such further light as has been afforded by the experience and observation of the six years, which have intervened since the foregoing was written. We suppose our inquirer to ask, what do you assume as needing no proof? We assume,

1st. That there is a circulation of the blood.

2d. That the direction of its current is known; valves being so placed as to open the passage of the

pipes which conduct it, so that it moves freely in one direction, and cannot move at all in the opposite.

3d. That the velocity of the blood's current is unascertained, and is not uniform.*

4th. That so far as the circulation, irrespective of the lungs, is concerned, the principal force or forces, which cause the blood to circulate, enter the circulatory system at the aorta.

We suppose our inquirer next to ask, what is the problem to be solved?

The *problem* to be solved is, what are the motive powers which produce the circulation of the blood?

What does the writer of this work, asks the inquirer, believe to be the true solution of the problem? We believe,

1st. That the motive powers are chiefly the conspiring forces, the principal one chemical; the other mechanical. Thus far, we repeat from the first chapter.

We now add, that we believe that, although the

* A writer in the Encyclopedia Americana says, that authors vary in opinion as to the time of the blood's circulation, from twenty-four hours to three minutes. Dr. Arnott says, the velocity has been much overrated. The velocity is different in different climates, in different individuals, and in different positions of the body.

principal motive power after birth is the chemical, before birth it is solely the mechanical; but, that the mechanical gradually loses, and the chemical gradually gains during infancy and childhood, till in adult years the chemical power becomes proportionally much greater than the mechanical, and in fact is, ever after birth, the leading motive power.

We would convince the inquirer,

2d. That the chemical force is produced by respiration, which drawing into the lungs atmospheric air, its oxygen leaves the nitrogen to combine chemically with the carbon brought by the returning blood; and that caloric is set free by this oxidation or combustion. That the caloric thus set free, expands the blood in the lungs. It must therefore move, and on account of the valves, it can go in no direction but towards the heart's left ventricle, and thence into the arteries.

3d. That mechanical power is furnished by the alternate contractions and dilatations of the heart. The heart also supplies the mechanism by which the chemical force becomes effective, especially in certain changes from an upright position, and gives by its contractions a pulsative movement to the blood in the arteries. We receive as truth,

4th. That the lungs, the heart and the blood, have

vital functions, and are therefore dependent on the nerves for their action; nevertheless, we are no more entitled to believe that the mass of blood circulates without reference to the laws of hydraulics, than we are to believe that the body's movements can be conducted without regard to the laws of gravitation. We believe,

5th. That capillary attraction aids the principal forces in conducting the blood through the minute tubes of the extremities, and that exercise is necessary to move the venous blood, and produce a healthy circulation; and further, that the venous blood receives an upward tendency from imbibing the caloric of radiation, as it begins to approach the region of the lungs. When it is at 72° F., it is at the point where water in vacuo is converted into steam.

SECTION II.—WHY THE HEART HAS BEEN SUPPOSED THE SOLE MOTIVE POWER, AND WHY IT IS NOT.

Suppose now, that the inquirer asks, how happens it, if such be the true motive powers, that ever since the discovery of the circulation, two hundred years ago, the heart has been supposed to furnish the sole efficient motive power. To this, we reply,

When Harvey discovered the circulation of the

blood, heat as a moving force was little known. The most vigorous spout of the blood he found at the aorta, and there was the heart, whose beat was communicated by the pulse throughout the arteries ; and the heart's beat would, therefore, naturally be first suggested as the power. But at this day when heat by expansion comes to be so much used as a moving force, and where on so many occasions it is found to be so far superior to impulse,* and when we have had full time to get over the astonishment which the discovery of the circulation naturally created, and to let marvellousness cool into sober reason, it is time we opened our eyes to see that the Great Artificer understood the value of expansive power long before his creatures discovered it. It is time for us now to dispense with a doctrine, which, to the common understanding of mankind, if they would dare to use it, must be apparently a monstrous absurdity. Dr. Arnott says the heart's force [that is, suppose it is that force which overcomes the resistances] must be estimated at sixty pounds, as it contracts to send the blood from the ventricles. But in its reaction it

* "A steam engine," says the French traveller, Chevalier, in his 'Letters on North America,' "has a complete respiratory apparatus which acts like our own, by expansion and compression, it wants only a system of circulation to live."

strikes the ribs with its apex. Think of a hammer in the thorax of sixty pounds force, which moves with a jerking motion upwards, and with an equally quick stroke back against the sides, and that as fast as one can count, viz.: seventy times in a minute. Suppose you were to take a hammer into your right hand, and strike with that force and velocity upon one of the fingers of your left, could you beat 350 strokes in five minutes? But the heart beats on night and day, sometimes for a hundred years without ever stopping to rest, and the side, which is of a sensitive substance, feels no pain or soreness, and if the person has been free from disease of the heart, he has scarcely thought, all that time perhaps, that he had a heart. But you may say, a heart is not like a hammer, it is soft. Yes, and is small besides, and is therefore altogether an unfit instrument for communicating such a force. There is mechanism in the bones and muscles, and we can understand how they compare with levers and pulleys, and by what means they play—nay, we can make useful machines on the same principles as those by which they operate. But no mechanician has attempted any such thing with regard to the heart, but all acknowledge that its force is an enigma, an anomaly, a wonder of wonders.

And why should the Wise Architect put such hard service upon the little heart? Surely there is another strong and active servant in the house, who, if put in the right post, may do this work without the least inconvenience or injury, one whom we know to be skilled in exactly this kind of labor, for we have tried *heat*, and know it to be an agent of motion, strong in operation, and if need be, gentle as strong.

But can we suppose that heat is present at the right place? says our inquirer. We may not only suppose that it is, but we can make no other supposition without improbability, and a violation of the most common facts of chemical affinity. Then how can we hesitate to believe that heat is designed by the Creator as the principal agent in carrying on the circulation?

"But," says the inquirer, "there is in some late chemical works a theory stated of Dr. Milne Edwards's, which teaches that heat is generated equally over the whole body." We shall notice this theory at large hereafter, and fully show its absurdity according to the laws of chemical affinity. But, in the meantime, let common sense decide. If the solids of the body were constantly receiving heat by absorbed oxygen burning carbon in them, then at death the lungs should be the first place to become cold,

and the solids of the body the last, or at least the body would all become cold at once. But does not every one know that when the death-coldness comes on, it comes first at the extremities and last at the vitals? If so, then it is at the vitals where the heat is generated. Does not any one know from his constant sensations, that the heat of his system comes from the vital organs and goes off at the skin's surface?

SECTION III.—THE HEART BELONGS TO THE LUNGS RATHER THAN THE LUNGS TO THE HEART.

If there be such a chemical power as we have supposed, it would start from the same point into the general circulation as that produced by the heart's action, viz.: from the aorta. Therefore no proof can be derived against the existence of the chemical force supposed, because the aorta springs also from the lungs; and moreover, the chemical force, if it existed, would require just such a mechanism to make it effective, as the heart, furnished by its valves, its contractions and dilatations. "The place of heat in all animals," says John Bell, "is determined by that of the lungs. Where they are, that is." The aorta

then springs from the lungs through their proper mechanism, the heart.

No argument against the chemical force supposed, can be derived from the pulsative movement which the heart's action conveys to the blood in the arteries, for the same movement would be produced by its contraction if the chemical power was the chief cause of the blood's velocity.

The experiments on a fluid in a long tube which we formerly described, showed that while the fluid was circulating by a chemical force without pulsation, a gentle pulse was given to it by the contraction of a hand on an elastic part of the circulating tube. This pulsative movement, as I well recollect, was instantaneously felt at the opposite part of the tube, a distance of about five feet. Another use of this apparatus, which I now describe from recollection, is in point. When there was no heat, and no current from expansion, we produced a slow and labored current by forcible simultaneous contractions and dilatations of the hands on the india-rubber tube between the valves. In this case, although the pulsative beat was quick, hard, and very distinct, the circulation was slow, the colored powder used for observation, not moving so rapidly along the glass portions of the tube, as when we had a current from expan-

sion with a much less forcible pulsation. Pulsation then does not measure the velocity of the blood's current, and is not, therefore, the principal cause of that current. There is no doubt that the blood in the arteries of the head moves more rapidly than in those of the feet; yet the pulse is the same. Strength comes from a vigorous circulation, yet in some fevers where the pulse beats quickest, there is entire prostration.

SECTION IV.—OPINIONS OF WRITERS, ETC.

Let it be allowed that we have removed these two objections, viz.: that concerning the first springing of the blood into the general circulation at the heart; and second, that of the pulsations of the blood as being derived from the heart: we shall find expressed in one way or another, a general opinion among those who have examined the subject, that there is a strong improbability in the heart's action furnishing the cause of so great an effect as the circulation of the mass of the blood against the obstructions which it must encounter. Dr. Roget, a late as well as an able writer, declares himself of opinion that the heart's action alone is not adequate to produce the circulation. We will quote his language as to the great

resistances which the force springing from the aorta must meet; and let the inquirer, as he reads, stop and reflect how the expansive power, if allowed, would meet these various obstructions and overcome these difficulties:

"It will be quite evident," says Dr. Roget, "that a very considerable power is required, in order to enable the heart to propel the blood through the arteries, when we consider the enormous resistance opposed to its progress, and when we also take into account the great velocity given to it in its motion. The column of blood already contained in the arterial system, must have its velocity accelerated, in order to admit of the passage of fresh blood into the aorta. The arteries require also to be distended for the admission of this additional quantity of blood every time that the ventricle contracts. The angles and flexures which the blood is obliged to follow in its course through the vessels must be the causes of retardation, and must be productive of a loss of force, which the muscular power of the heart is ultimately called upon to supply. The operation of all these retarding causes is so complicated, that we need not be surprised at the problem of the force exerted by the heart having baffled the skill of the best mathematicians, and their calculations being so widely differ-

ent from one another. Thus while Keil estimated the power of the left ventricle at only five ounces, Borelli calculated that its force could not be less than one hundred and eighty thousand pounds. Dr. Hales computes it to be exactly fifty-one pounds and a half; while Tabor concludes its amount to be one hundred and fifty pounds. Such irreconcliable results show the futility of most of the reasonings on which they are founded."

Dr. Roget further tells us that a query has arisen whether the arteries by their elasticity do not make up the deficiencies of the heart's power, and he inclines to believe that they do. But having no valves except at the entrance of the aorta, and no vermicular motion, any contractions which they might make, except at the aorta, would send as much blood backwards as forwards. That any such power is afforded by the arteries is denied by Bichat, Arnott and others. We have no objection to allowing that some aid may thus be received; but still maintain that the expansive is the leading power.

CHAPTER III.

NATURE OF THE MOTIVE POWERS OF IMPULSE AND EXPANSION.

SECTION I.—NATURE OF THE TWO MOTIVE POWERS, IMPULSE.

To place the great theorem of the circulation within reach of the laws of hydraulics and in its most simple form, let us for the present put out of the question all considerations of the circulation in the lungs and liver, and the branches of the great arteries and veins, and suppose the circulatory system as an endless elastic tube of the form of a long elipse,*

* With regard to the lungs, if the theory of force by expansion is true, their own circulation would be carried on by this power, with a slight force of impulse from the heart, to open and close its valves. The circulation of the liver, too, I regard as peculiar and functional. In this case, the circulation from the heart, through the aorta to the vena cava, and back to the heart, would be all we have to account for, and this may not be unaptly represented by one elastic tube. The double heart does not change the condition of the problem. The use of the right side of the heart is, to send the blood to the lungs. Without the lungs, the vena cava might have discharged its contents into the left auricle.

and examine the manner in which the forces supposed, would operate to circulate a fluid, with which we will suppose this tube to be filled. The circumstances by which the human system varies from such a tube, and the effect of these variations, may either be considered as we go along, or be referred to afterwards.

And first let us consider the force communicated by an impulse produced by the contractions and dilatations of an organ (the heart) endued with a contractile movement. That such a movement, if sufficiently powerful, may be made to produce a circulation where a valve is placed near or within it, needs no proof. The question now before us is, in what part of this tube must this force be introduced to operate to the greatest advantage, the tube being kept upright, and a valve placed near it, which will give direction to the current. The resistance to be overcome is, the gravitating pressure of the two columns of the fluid which balance each other at A and B, but whose momenta being concentrated at A, no circulation can be produced until that point is moved.

1. And first, such a force could not operate at either end of the ellipse, since from the form of the

tube, the force of the impulse must in that case be lost by the reaction of its sides.

2. Suppose a heart endued with a contractile power placed at H, with a valve below it opening upwards, one quarter of the fluid being above, and three quarters below, which is about the proportion of the blood circulating above and below the heart in the human body. As the heart contracts, a part of the fluid will be displaced and forced upwards with a wave-like motion. Another part of the fluid will be pressed with a condensing force against the valve V, which, as soon as the heart dilates, will spring, with a force proportionate to its compression, directly from the side of the valve giving direction to the current, and also a distinct pulsation, and it will produce a vacuum which will cause the fluid to rise through the opening valve; or in other words, a suction power will be produced. But the gravitation of the column of fluid from H to B, is opposed to the force of the impulse given by the heart, and will destroy a portion of it. The gravitation of the column from V to A is opposed to the suction power below V, and will

operate to destroy it in whole or in part.* Therefore, the impulse acts at H with disadvantage. And for the same reasons it must work at a disadvantage on any part of the column A V B, where the valve being placed below, the contractile movement would give the first spring of the current an upward motion. And again the force of the given impulse will be diminished in proportion to its distance from the point A (going with the current), because force will constantly be lost by reaction against the sides of the tube, and no circulation can be produced until the point A is moved. The force at H being distant from A by the length of the tube from H through B and I, it follows that the point H is not the proper point to introduce a contractile power, if it is by that force principally, that a circulation is to be carried on. Since infinite wisdom has placed the heart in that position in the human system, it is not therefore probable that this is the principal force which is designed to carry on the blood's circulation.

* Dr. Arnott says, the veins are pliant tubes free to collapse, and no pumps can lift liquid through such. A practical illustration is afforded by putting the point of a syringe into an eel-skin or vein, filled with water, and then trying to pump up the water. The result will be, that the fluid close to the mouth of the syringe will enter it, and then the sides of the pliant tube will collapse as a valve against the syringe, making an end of the experiment.

3. Let the point I now be taken as far from the bottom of the tube as H is from the top, having a valve above it opening downwards. The impulse being given as before, a portion of the fluid is, by the contraction, pressed downwards, and another portion pressed upwards against the side of the closed valve, which, on the dilatation of the organ, starts forward with a leap, and the valve pressed by the column above, instantly opens, and thus the impulse below the valve, and the suction power above, both conspiring with gravitation, its whole force strikes against the opposing column concentrated at A with only a small deduction for the reaction of the tube from I to A. This then is the point at which the power of impulse would work to the greatest advantage in carrying on the circulation. And this the Creator has made the natural position in that state of existence when the heart does furnish the sole power in carrying on the circulation.

But as impulse is a force which operates on fluids in the mass, and as fluids press according to the perpendicular height of their columns, and man, from his erect position, has long columns whose pressure

must be overcome before circulation takes place, impulse, therefore, seems not the most suitable power. But in the human system it will operate best (having least pressure to overcome) when the posture is recumbent, as no column of blood will then have more than an inch of perpendicular height. Authors have said much of the displacements of the heart.

Suppose the heart to be so turned that the valve V, which gives direction to the current, makes an acute angle with the side of the tube (here representing the aorta), the force of the current in this case would be spent against the side of the tube A. Since such displacements of the heart are, as all anatomists tell us, very frequent, the circulation still going on without material derangement, therefore, some other power besides that of impulse by the heart's action, is the leading motive power.

SECTION II.—NATURE OF THE MOTIVE POWERS.

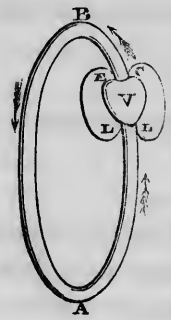
EXPANSION.

Expansion by heat operates not by moving masses of fluid, mechanically, with a force exterior to them, and, therefore, resisted at every step by whatever

resists the column in the direction of the impulse given; but it is a chemical power operating among the particles of the fluid, requiring elastic conductors, and not subject to lose force by resistance of the conducting tubes, in the same manner as the mechanical force, and from alternate expansion and contraction it can be made available as a force when needed, and annihilated where it would be resistance rather than power. Expansion, therefore, seems by its nature and adaptation to the circulatory system to be the force intended.

We proceed to show the nature and operation of a power created by expansion, and to consider at what point in the tube this power would be best introduced.

Suppose, as before, the same elliptical tube to be filled with fluid and in an upright position. Suppose further, that a vessel, L (representing the lungs), is attached at any point as C, which opens into the tube, and that this vessel contains about one-fifth of the whole quantity of the fluid which fills the apparatus. Suppose that within the vessel some chemical process is going on, which communicates heat simultaneously to



the different parts of the fluid which the vessel contains. The lighter particles, as soon as they become heated, will escape at E, and pass upwards towards B. A suction power will be produced from C towards H, and if the expansive power which drives the fluid upwards from C to B, and the suction power below C, be sufficient to overcome the pressure of the column B H A, a circulation will be produced.

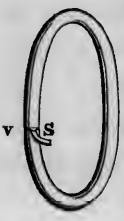
This is also abundantly proved by the experiments formerly stated (see page 15); and the principle is now applied to the warming large buildings, by circulating through them warm water in pipes so arranged that the fluid moves upwards from the place where the heat is generated, and cools before its return.* And further, since the same causes must produce the same effects, we have proved that this circulation thus produced will continue so long as the tube above C is kept upright or approaching thereto, and a proper balance is preserved between the heat generated at L (see fig. on preceding page), and the coolness produced by its transmission through the opposite side of the tube H. And since the alternation of the fluid from heat to cold is the cause of this circulation, the greater the change effected in the temperature of the fluid, the more rapid will be the

* See Bridge's Chemistry.

circulation, for the effect must be as its cause. Or, in other words, since expansion is the force, the greater the expansion the greater must be the velocity, and vice versâ.

Having demonstrated that a circulation may be produced by expansion being introduced on one side of the tube, and the fluid, by the position of the tube and the absence of obstructions, being left free to rise from the point of its introduction, we next inquire at what part of the side of the tube should be its first spring.

It is apparent that if the expansive power were introduced at B or at A, it would have no effect to produce a circulation, but would spend its force on the part of the tube opposed to its upward progress. The expansive power could not, by any arrangement of valves, produce a circulation from its starting point downwards. In this case it could never, in any containing tube subject to rupture, overcome the force of gravitation. For, suppose the expansive power introduced at S and a valve opening at V, the problem is materially altered by the nature of this force from the same case, where an impulse by contraction should be introduced at the same place. For, the contracting organ as it

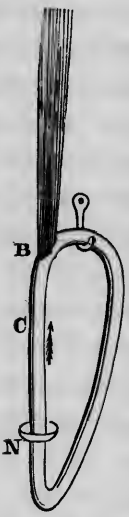


closed would afford an impulse whose nature would be to send a part of the fluid downwards, press a part of it in a condensed state upwards against the closing valve, and this on the dilating of the organ would spring to its natural condition, and thus make a vacuum which would allow the column above to descend through the opening valve, and thus by reaction the whole force of the impulse, except that lost against the sides of the tube, would go to produce a downward circulation; and to the force of the impulse the whole of the gravitating pressure of the fluid, as formerly seen, is to be added as motive powers to act against the point A; but let the only force supposed be the expansive power introduced at S; then, this being a constant force and only acting upwards, so far from allowing the valve to open it, would but press it the closer, and on the continuation of the expansive force, any containing vessel material to our purpose to consider, must burst to give way to its upward passage.*

For, as soon as any quantity of the fluid shall be driven beyond B or drawn away from A, the whole force of gravitation on the side of the tube B M A will conspire with this force, and the heated particles

* This represents the danger the human system is in, by hanging the head downwards.

being constantly supplied at E, the circulation will go on by the combined forces of gravitation and expansion, provided the tube be sufficiently long to allow of the loss of caloric, or some cooling agent be applied to the part opposite C, so that a proper balance shall be kept up between the heat of the fluid in the vessel and the coldness of the opposite side.



But that no injury should occur to the tube, the place of introducing the expansive power should be somewhere near the point B. For, first, if the expansive power be introduced on the lower part of the tube as at N, so much force must be applied to overcome the pressure from N to B, that there would be great danger of bursting the tube at B. This I accidentally demonstrated in the course of an experiment with a similar apparatus to that in the figure. Its length from N to B was about two feet. I applied the heat at N. The fluid did not move as when, in former experiments, made with a tube of the same form. I applied the heat at C, but while I was intently considering the subject, I received a shower of water on my head; the tube bursting at B with such force that it threw

up a stream of water eight feet to the ceiling, which of course fell upon whatever obstructed its downward progress. This shows also that a circulation, if produced without rupturing the vessel, by the expansive force entering at N, would be more labored and with greater difficulty restored, if interrupted, than if it came into the tube at C.

And again: if the expansion was applied at N, there would be a waste of force, not so much on account of the greater length of the tube from N to B than from C to B, but on account of the peculiar nature of the force; for, from the rapid transmission of caloric, it would not only diffuse itself throughout the fluid, but go off at the surface of the tube. Therefore, the opening of the lungs through the heart into the aorta is the proper philosophical point at which to introduce a power by expansion into the circulation; and since of the two motive powers which come into the circulation at the aorta, that by impulse acts at a disadvantage, and that by expansion has the system perfectly adapted to it, we argue that the Creator designed the power of expansion as the leading motive power.

SECTION III.—COINCIDENCE OF THE FORCES OF IMPULSE AND EXPANSION.

Having now taken a separate view of the two forces, we are prepared to understand their joint operation, and some of the more important variations caused by the actual state of the circulatory system in the animal body.

And first we are to consider that although the circulatory system in its state of activity is upright or nearly so, yet in rest and sleep the recumbent is the natural posture; and although a great variety of exercises are to be performed by which every possible position may be required, yet the one with the feet upward and the head depending is adverse to life.

And here again I protest against the statements of writers which suppose the velocity of the blood's current in a complete circulation to be no more than three or four minutes. If we might consider the forces as settled, we should then gain data to calculate the velocity which, with observations on the healthy phenomena of the changes occurring in the living subject, would approach to certainty. But the time taken in the general circulation of the whole

mass must ever be a difficult problem, for the circulation varies, 1st, according to the density or rarity of the atmosphere we breathe; 2d, according to the healthy or unhealthy state of the lungs and other parts of the circulating system, or of the skin; and 3d, it varies as to its rapidity in different parts of the system from the head, where the circulation is quickest, to the feet, where it is slowest.

So gentle is the movement of the blood through the system that the whole mass of human beings had lived more than five thousand years before they suspected that it circulated at all, and probably one half of mankind are ignorant of the fact to this day. Hence we argue against the supposition of the great rapidity of the blood's current. Whatever the physical course of the circulation may be, it is as mild in its normal state as the breathing of a mother upon the face of her infant.

These remarks will lead us to notice how bountifully the gentle raising of the temperature in the lungs from warm to warmer, conspires with the light elastic motion of the heart to lead on gravitation itself, the constant opposing force, to aid in producing a circulation; and one which is so balanced that when, from change of position, one force loses advantage, the other gains it.

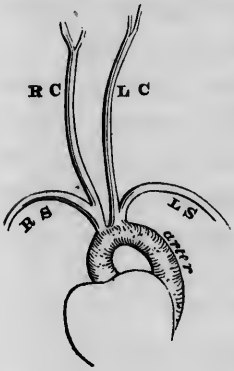
We have said little respecting the elasticity of the lungs, arteries and veins. It is, it has been remarked, the opinion of some writers of the present day, that the elasticity of the arteries affords aid to the circulation. Be this as it may, one thing is certain, viz., the vast pressure of the atmospheric air on the human body. This would not allow of expansion in the blood-vessels unless some great pressure should occur in some part of the system, when if there were no elasticity in the blood-vessels, they would be ruptured, or the circulation stopped ; and when, extraordinary depletion occurred, that condition of our being which requires that the blood-vessels shall in no part be empty, could not be fulfilled unless these conductors were elastic.

But the wisdom of Nature will be best seen by observing the manner in which the two forces operate together. If the expansive force issuing from the lungs into the heart's left ventricle, were only sufficient to carry the blood upwards to the bend of the aorta, and send a brisk circulation through the carotids and subclavians to the head and arms, it were a force of incalculable value, for it would relieve the heart where it most needs it.

"The superior importance of the brain," says George Combe, "might be inferred from a fact dis-

covered by anatomists, that although the brain weighs only one-fortieth of the whole body, it receives one-tenth of the blood which is sent from the heart."

But how, without assistance, was the heart to force all this blood into the head? The current given by impulse in the aorta must turn off at angles to enter these upright and smaller arteries. (See fig.) But allow a power by expansion, and the head would naturally be supplied with the greatest quantity of the best heated blood in the system. We have then a force of incalculable value, and one which will take from the impulse the great difficulty in the first part of the blood's course. Now suppose only half a cubic inch of expansive power* to be generated in the lungs at each inspira-



* This amount is taken from the computation of a gentleman of talent and chemical learning, on the data contained in the first chapter. But no account was here made of the warming of the upward current of the blood by the caloric radiated from the lungs, nor any notice taken of the very significant fact that the force works in vacuo, where the point of temperature at which water springs into vapor is 72°, 6° below mean temperature.

tion, viz., ten cubic inches in a minute, would not even be sufficient to effect these purposes, and would it not send the circulation briskly through the carotids and subclavians? Would it not send the most rarified part of the blood to the head, and the next most rarified to the arms? Do not these inferences coincide with the facts? And how could the impulse given by the heart alone produce these results?

The fluid being conducted round the bend of the aorta, what next do we find? The strange phenomenon of the blood's circulating in the arteries without any perceptible gravitation. So say the writers, and so it must be, for otherwise, as the capillaries conduct it deliberately away, if all the force of gravitation operated on this column the limbs would swell, and the circulatory system become deranged, notwithstanding the check which the current receives from the branching of the arteries, and the consequent enlargement of capacity in the circulating system. We want a force then in the descending column of the arterial blood to lift upwards against gravitation, and what force could that be but gravitation's universal antagonist, caloric? in short, exactly that of the expansive force which we have supposed.

SECTION IV.—THE HEALTHFUL BALANCE OF TEMPERATURE. HOW PRESERVED.

It is but just enough blood which is wanted, at the entrance of the current into the capillaries, to supply them with what they can carry off. But the force at the lungs is a force varying with the density of the atmospheric air inspired. A dense atmosphere affords more oxygen, and produces more expansive power, and more animal heat. But here comes a danger and a difficulty, viz., that this heat should sometimes pass the capillaries by means of the circulation, and so the blood return too much heated to the lungs. This would have two bad consequences. 1st, the whole amount of blood would become heated above the mean temperature of 78°, the ascertained measure of health; and 2d, the circulation by the expansive power would be enfeebled, and at length the venous blood becoming equally heated with the arteries, the circulation, so far as produced by the expansive power, would cease; and since the heart's power alone cannot sustain it, life would become extinct. For, since the course of this force is the change of temperature from the coolness of the extremities to the heat of the lungs, the degrees of

change will be the measure of the force ; and if the change of temperature was nothing, the force would be nothing. This was proved by the experiment related page 15, where the circulation went on briskly until the liquid in the long tube became equally heated, at which time the circulation ceased; but was restored on the application of snow to the part of the tube most distant from the vessel, where the expanding force was generated. But nature has made as signal provisions for cooling the system at the surface, as for heating it at the lungs. And 1st, the same dense air which produces the most powerful internal combustion, conducts off the greatest amount of caloric at the surface, and thus produces the most vigorous circulation, and the reverse. And 2d, a portion of caloric is constantly carried off at the skin by a perspiration, which varies in degree according to the danger of the system's becoming overheated. This coincidence of facts with the principles of the expansion theory not only proves the truth of the theory, but it shows the futility of arguments against it, based on the supposition that it does not show expansive power enough. There is, in certain cases, danger of too much, as these provisions of nature plainly indicate.

But since the system must vibrate from heat at the

vitals to coolness at the extremities, in such a manner as to keep the mean temperature at 78°, it follows that coldness at the vitals must also destroy the circulation. That this is the fact, the phenomena attending death by freezing sufficiently attest.

And let us here mark the kind care with which our Creator has guarded the circulation in this respect, by instincts the most remarkable and the most constant of any with which our animal nature is endued. And first, we notice instinctive respiration. We must have oxygen to support the internal combustion, and we must have it every moment; and nature has made us to feel that the most pressing of our necessities is, to breathe atmospheric air. Secondly, we are endued with a feeling of pleasure in that comfortable warmth, which is the measure of healthy vibration between internal heat and external coldness, and on the contrary with a feeling of pain and suffering from extreme injurious heat, or dangerous coldness. This feeling is intense when that shuddering cold comes over us which endangers the continuance of the circulation. Again: we must not only have the supporter of combustion, but we must have the combustible daily renewed. This we derive from our food and drink, which the instincts of hunger and thirst oblige us to take. After the

blood has passed the arteries it is led into the veins by capillary attraction, and then comes the last grand difficulty in the circulation. When the blood has left the capillaries, how is it to be lifted back to the heart and lungs? And here we must again notice that property of caloric, by which it is transmitted by any heated body to whatever bodies lie contiguous to it, until their heat is equal to its own; and by those bodies to be in like manner transmitted to others; and so on, until it goes off at the surface. By this law of the transmission of caloric, all the organs next the lungs would have the same heat as the lungs; and thus all the inner parts of the body would have the transmitted heat derived from the lungs. As soon as the blood of the capillaries is led on its course by capillary attraction, being driven onwards by the arterial current, then as it passes upwards it soon begins to be warmed, and of course expanded by this transmitted heat, and as the parts of the body are more and more warmed as it ascends, it would be more and more quickened in its upward course; and as the effect of gravitation would be checked by the branching out of the system from the top to the bottom, so the ascending current would be accelerated by the uniting of the branches and the lessening of the general capacity of the circulating

system. But the returning current occupies the more space, and therefore has less velocity than that going out from the heart and lungs. All muscular exercise displaces blood from the veins, which, on account of their valves, must move towards the heart and lungs. These causes, together with the suction power, appear to be fully sufficient to account for the venous circulation.

There is one consideration respecting the valves which affords evidence of a design to aid the blood's circulation. The valves of the heart cutting the columns of blood into shorter columns, their pressure is diminished, and the same remark applies to the valves in the veins.

Some of the most remarkable of the variations in the operation of the forces is that caused by change of *position*. And first, with regard to the horizontal: and here we see the wisdom and goodness of the Creator in giving us sleep—the night to sleep in, and the instinct of weariness to compel us to lie down. Let us now place horizontally one simple elliptical tube which we have all along supposed upright, and consider the operations of the gravitating fluids when in a horizontal position ; and here, instead of long perpendicular columns of fluid, we have only the diameter of the tube for the perpendicular pressure, and

that is not in any case much over an inch. Then we have the upward movement of the expansive power, to balance gravitation, and take off pressure from the base of the containing vessels. So when the human body is thus laid recumbent, slight accessions of force will keep the current in motion; and as the heart's power works best in this position, it is probable that it is proportionally most active at night, and least so during the day, when the expansive power works to the best advantage.* Thus the heart may rest during the day, and the lungs during the night. That a change of forces takes place in changing from upright to recumbent postures, is clearly shown by the changes in the breathing and in the pulse. This will be especially apparent in older persons and in invalids. The pulse gains from four to six beats in a minute by rising up. But if it is the power of expansion which we depend on for daily activity, we must for this reason regard it as the leading motive power.

SECTION V.

The principle that the expansive motive power works in vacuo, will not apply equally to every part

* See Article on Sleep page 122 et seq.

of the circulatory system, on account of the different situations in which different parts of the system are placed with regard to the pressure of atmospheric air. For if the blood were contained in elastic blood-vessels, and these freely exposed to the pressure of atmospheric air, the expansion of the watery particles into vapor would require nearly the same degree of heat as if they were exposed to the air in an open vessel. But this is by no means the case. Within the cranium the blood-vessels are wholly defended from the atmospheric air. The arteries are rather contractile than elastic. The aorta and its great branches are shielded from atmospheric pressure by the bones of the trunk, and theirs are paths cut out of solid bone. Concerning the lungs, let any one who doubts that they work in vacuo, examine a drawing in the last part of the first volume of John Bell's Anatomy, and see there the effect of a wound in the side, by which the air of the atmosphere is suffered to come in contact with the exterior of one of the lungs. They will there see the lung collapsed and apparently shrivelled like a bladder. The veins are nearer the surface, and sometimes are pressed with the full weight of the atmosphere, but when they become deep-seated and unite in the great trunks in the central parts of the body, then the bony

structure will defend them also from atmospheric pressure.

There is a pressure of gas within the air cells of the lungs which, it appears to us, has never been duly estimated. For if the combustion of carbon takes place in the lungs, then not only will the fluids expand, but the gases also, and much more. And I think any one may be convinced that the air which he breathes is not enough in the state in which he receives it to swell his size, as a long breath held a moment will do, and to change his specific gravity, as every swimmer knows is the case. Is not the human body increased in its bulk during a full inspiration, by as many cubic inches as it would require for the contents of a small bladder? yet how little would one breath do toward inflating a bladder? This phenomenon, viz., a change in the size of the trunk, for which the bulk of the inspired air does not account, must be owing to the expansion of the gases in the air-cells in the lungs, when chemical change takes place and caloric is set free. This inward expansion of gas would prevent the effects of outward pressure on the circulatory system.

It appears to me that the expansion of gas by a chemical action accounts, at least in part, for the alternate heaving and depression of the chest in re-

spiration. The lungs have been compared to a bellows. But a bellows requires a power without to work it. The lungs have the power within. Suppose that within a bellows there existed a chemical agency which, after having a little air drawn within its reach, suddenly changed it and evolved caloric. This would forcibly expand the sides of the bellows. But the reaction of the sides would soon overcome the inner pressure, and they would return with some force to their natural position, and expel from the nozzle the heated air. But the force of the reaction being expended, the external air, denser and heavier, would naturally be drawn into the nozzle to supply the inner vacuum, the sides expand again, and so on as before.

If there is reason in this statement it goes to prove the fact of the creation of an expansive power by respiration, which, if it affect the gases, must also affect the fluids, and become a Motive Power.

These operations of Nature, if we have rightly interpreted them, are to be regarded as gentle and gradual, since the breath is not at once drawn into all the air-cells of the lungs.

CHAPTER IV.

OBJECTIONS ANSWERED, &c.

SECTION I.—OBJECTIONS TO THE THEORY OF FORCE BY EXPANSION, BY DR. W. F. EDWARDS, REVIEWED.

The objections to a motive power by expansion, which I shall chiefly notice, are from the late Dr. William Frederic Edwards, of Paris; to whom a copy of the theory as stated in the first part of this work, was addressed in the autumn of 1839. Indeed, the objections of Dr. Edwards, taken in their full extent, comprise, as I believe, all, which scientific persons will be likely to bring against the theory. They are contained in a letter to me, written from Versailles, in the spring of 1841. I shall give them in Dr. Edwards' own words, in an extract from his letter.

"This theory must be treated like all physical theories, and measures must be applied as a test of its justness. There is no doubt that heat produces expansion, and consequently motion; but it is indis-

pensably necessary to measure that motion, in order to ascertain whether it can produce the quantity of motion experienced in circulation. Now, this has not been done. But in the second place, the physical apparatus cannot perform the function solely by means of heat, as you yourself are conscious of. But the impossibility does not disappear by adding the property of opening and shutting the valves; for, pressure being equally established by means of the dilatation of the blood, it might equally flow back when the valves are opened. We are, therefore, led to admit a successive contraction and dilatation of the heart, even in the hypothesis of heat being useful to circulation," &c., &c.

It strikes me that to a candid mind, which has attentively marked in the foregoing pages, with undoubting faith in the wisdom of God, the manner in which his arrangements in the circulatory system evidently pre-suppose an expansive power generated by respiration and to issue from the lungs; that such a candid reader will scarcely be able to withhold his full assent to the actual existence of the force, and will only wish to know whether that supposed is a *possible* force. To this we can reply in the words of the objector, "there is no doubt that heat produces expansion, and consequently motion."

But Dr. Edwards says, that it is necessary to "measure the force in order to show that the force produces the required motion;" or in other words, to carry the theory into the quantitative method. It is almost amusing, when those who believe that the circulation is carried on solely by the heart's action, of which no one ever thought of showing beforehand by its appearance and dimensions what it could effect—it is amusing when these gentlemen ask for exact measures of force in regard to a power by expansion. It is true, there are calculations of the heart's impulse, made by the most eminent physiologists to this day, and varying from units of pounds through tens and hundreds up to thousands. And how are these various estimates obtained, by which they show the quantity of force furnished by the heart? Why, they first take it for granted that the heart's action is the sole force which carries on the circulation, and then assuming the velocity on such experiments as those of Dr. Hales, which are vitiated by the contractile power of the wounded arteries, then they calculate the resistance, and proceed to infer that the heart's power must be sufficient to overcome all this resistance in the assumed time; and this is the heart's force, which they thus bring out in the conclusion in numbers. If these gentle-

men will allow me the same liberty which they take to themselves, viz., that of making my own data, I could make a calculation and carry it out in quantities, connected by algebraic signs and long rows of decimals. But to what honest purpose can it be, to give the form of demonstrations in the exact sciences, to subjects where the data are uncertain, and from their nature must ever be so?

In this theory I assume the heart's force as one of the motive powers, its exact quantity wholly unknown and unappreciable, and I allow that there is an accelerating force in the capillaries. But who can tell exactly what it is? The resistance to be overcome in producing a circulation in the human body is also unknown, and unappreciable in numbers, as is also the exact time of the circulation. So, then, in order to know how much "motion," as Dr. Edwards expresses it, I must show in order to ascertain if it can produce "the quantity of motion exercised in circulation," I must first show the amount of two unknown quantities, viz., resistance and time, from which, at least, two other unknown quantities, viz., the force of the heart, and the action of the capillaries, are to be subtracted; a problem which Sir Isaac Newton himself would have found it hard to solve.

SECTION II.—METHOD OF REASONING BY INDUCTION. CHOOSE TO REST ON EXPERIENCE RATHER THAN EXPERIMENTS.

But I object to the requirement of proving by quantity, and to the assertion that unless I do, I prove nothing. It is at variance with the established rules of logic, founded on the Baconian method of induction. Let us take an example. An inexperienced housewife fills a kettle full of water and places it over the fire; she finds that as the fluid begins to heat, it runs over the sides of the vessel containing it; at first she thinks perhaps that she has not placed the kettle in a proper position, but on filling it full another time and carefully adjusting it, the same effect again occurs. She then begins to suspect that the heat expands the fluid, and as she observes she finds that a fluid whenever exposed to the action of fire does increase in bulk. Must she, with these invariable phenomena, refrain from any conclusions concerning the cause of the overflow of the vessel, until she can in mathematical numbers show exactly the quantity of expansive power needed to produce the effect? She knows enough for this purpose when she knows that heat applied to a fluid in all circumstances is

followed by this effect, and hence she is logically entitled to conclude that heat is the cause of the expansion. And if we suspect that some person wishes to so apply the principle of expansion as to produce a circulation, as we perceive that this person is at the labor of procuring fuel, putting it in its proper place, arranging a circulatory system, &c.; if no other important object should be known why he took all this pains, a looker-on would be justified in believing that he did it with the express intention of circulating the fluid. So we, when we see in the human system a great effect to be produced, and one on which life and activity depend, viz., the circulation of the blood; when we know that this may be produced by expansion; when we see a vessel, viz., the lungs, constructed and situated exactly as such a vessel should be for generating the force, and tubes and a machinery for carrying on the circulation; when we find that oxygen by breathing, and carbon by food, must constantly meet and combine so as to produce caloric in the lungs, we are entitled to conclude that the Creator has made these arrangements for the express purpose of producing a circulation by these means, and we are entitled to this further conclusion also that the means are adequate to the end.

SECTION III.—HEAT NECESSARY FOR THE DOUBLE PURPOSE OF PREPARING THE BLOOD AND CIRCULATING IT.

Nor will this conclusion be invalidated if we find (pursuing the allusion before stated) that the housewife fills a circulating apparatus with milk which she wished to warm for converting it into the solid substance cheese, and that the circulation is to carry this warm milk to the dairy, there to be acted on and curdled by an animal substance and made to nourish the household. Respiration, although the necessary means provided for kindling and keeping up the fire, that is, to produce the expansive power, has doubtless another office, viz., to fit the venous blood for arterial circulation. But how is this done? By supplying oxygen? But oxygen is no element of nutrition. We know of no use of oxygen in the lungs but to produce and keep up heat. As to the change in the blood's caloric, we know of no ultimate good that it effects, and are hence led to conclude that it may be of as little significance as the color of the blossoms on an apple tree are to the production of its fruit. Beautiful colors speak of a Creator so kind that his own hand spreads forth pictures to please his children. We believe, then, that to produce heat in the

system is the great object of respiration, and that heat is produced for the double purpose of fitting the blood to be converted into solids and of carrying the same revivified blood to the place of destination.

Heat alone changes the color of venous blood to bright red. This I ascertained by experiment. The change of the blood's color in the lungs proves the superior temperature of the lungs. For if the red color take the place of the black because the carbon is burned out of the blood, then this proves the combustion at the lungs for which we contend. If, as some writers have asserted, the red color is the consequence of the chemical combination of some important substances before existing together in the blood, then they must combine in the lungs rather than in the veins, because there was more heat at the lungs to quicken chemical action.

Why then should we not conclude that it is the action of heat on the blood in the lungs which is the essential agent in preparing the venous blood to become arterial? What is necessary to apply to animal and vegetable substances to make them fit for nutrition? Heat, and nothing but heat. A high degree of heat is necessary in the first instance to be applied to these crude substances, but why not conclude that in the refined state in which the elements of nutrition

are found in the venous blood when it comes to the lungs, that all it then wants is a second and slighter heating. And do not the elements of the blood indicate this? Albumen is acted on at a low temperature. Milk must be warmed before it will curdle into cheese. And why may not the warming of the blood in like manner be essential to the formation from it, of the solid parts of the body—the bone and the muscle.

SECTION IV.—OBJECTIONS ANSWERED. PRESSION NOT EQUALLY ESTABLISHED.

We come now to Dr. W. F. Edwards's second objection to the theory of force by expansion. It has reference, doubtless, to the opinions of his brother Dr. Milne Edwards. It assumes that the "physical apparatus cannot perform the function solely* by means of heat," and further, that the impossibility does not disappear by adding the property of opening and shutting the valves; for, *pression being equally established* by means of the dilatation of the blood (that is, its equal dilatation in every

* Dr. Edwards seems to have forgotten that the theory to which he objects, distinctly asserts the heart's force as one of the motive powers.

part), it might equally flow back when the valves are opened." The whole force of this objection lies in the phrase, "pression being equally established." By it Dr. W. F. Edwards doubtless means to intimate that the combustion, which we suppose takes place in the lungs, goes on equally in every part of the body. This objection lies at the foundation of our theory, for if the heat of the blood were equally diffused in every part, the opening and shutting of the valves would no more cause it to produce a circulation, than the same machinery could effect a current by gravitation. But we regard the assertion that "pression is equally established," as wholly untrue. Indeed, we regard our theory as proved by what precedes, and if it is true, all its essential conditions, of which this is one, are true also.

Dr. Edwards's opinion seems to have proceeded on the unfounded supposition, that, if the carbon of the blood chemically combines with oxygen in the lungs, the heat of the lungs would be much greater than that of any other part of the body; and that a greater difference in respect to the warmth of the several parts of the body would occur, than we actually find. But facts and principles are both at variance with this supposition. For, if the animal heat of the body is mostly generated at the lungs, it

must, by the laws of transmission, go off from them in all directions until the heat of the adjoining organs becomes equal to that in the lungs, and so on, until it is lost by radiation from the surface. The heart lies, as it were, wrapped in the folds of the lungs, and the liver and stomach just beneath them, and their warmth should therefore equal that of the lungs. Then, the circulation is continually carrying out fresh supplies of heated blood, and by the same law of transmission, the heat of these currents is constantly going off to all the solid parts of the body; without it, they perish. If scantily supplied, their functions become deranged.

The experiment related in the first chapter of this treatise, shows how circulation brings every part of the circulating fluid to a temperature nearly equal, and the provisions which nature has made in the human body to keep comparative coolness at the extremities, shows intention that they should not become equally heated with the vitals. Again: if our theory be true, the head, except at the very surface, ought to be perhaps even more heated than the lungs, for the same reason that water in a vessel over a fire, is most heated at the top. The arms, too, ought to receive a brisk flow of the best heated blood

from the lungs; and the facts are correspondent in all these cases.

We do not make it a point, as some writers have done, to show that there is a difference in venous and arterial blood in respect to capacity for caloric. We only assert what common sense teaches, and the phenomena of pathology, as well as those of physiology, show, viz., that there is comparative heat at the vitals and coolness at the extremities. Does not every one know that the limbs freeze sooner than the trunk? And who does not know that when the trunk is absolutely cold, life is at an end? Yet, if heat is equally generated in every part of the body, why does not the heat go to the vitals from the extremities, as well as the reverse process? In natural death do the lungs first become cold, or does all the heat of the system fail at the same moment? It ought, if the heat were equally generated in every part of the system. But we know that at death the extremities are first cold, and that the coldness creeps gradually onwards from the extremities, and that the last retreat of animal heat is the region of the lungs.

There are cases, it is true, when perspiration having wholly stopped, the human system is in the condition supposed by the theory of Dr. Milne Edwards, when the whole body becomes equally heated

and " pression is equally established." But the man is then prostrate with a fever, and in such cases cures are effected by continually sponging with water to cool the surface by artificial evaporation, or if the case be urgent, the patient is enveloped in sheets wet in ice water. And when at length the languid circulation has carried the cooled blood to the lungs, it then springs into a healthy action. This fact proves that pression is not (in health) equally established. But the former proofs heretofore adduced showing that circulation is invariably affected by the difference between the maximum heat at the lungs and the minimum at the extremities, all go to disprove Dr. Edwards's assertion, and establish the principle for which our theory contends, viz., that animal heat is chiefly generated at the lungs and lost at the extremities. And if generated there, then it must be by respiration bringing oxygen to the carbon found and burning it at the lungs, which is the doctrine for which we contend.

SECTION V.—OXYGEN CHEMICALLY COMBINED WITH CARBON IN THE LUNGS, AND IS NOT ABSORBED.

The hypothesis by which Dr. Milne Edwards endeavors to account for the unfounded supposition

that every part of the body is of equal temperature, supposes that notwithstanding oxygen meets carbon in the lungs, and the returning breath shows that an equal quantity of oxygen to that inspired is returned in chemical combination with carbon, yet that it does not there chemically combine with the carbon, but permeates the membranes of the lungs, and goes by absorption into the blood, to be carried off by the circulation to burn carbon equally in all the several parts of the body. This is not only of itself extremely improbable, but if we allow that the vitals are warmer than the extremities, it is at variance with the plain laws of chemical action, one of which is that chemical processes are always quickened by heat. Then if the affinity of oxygen for carbon is such that it will combine with it anywhere in the animal body, it will surely go into this combination most readily where it is most heated, and least where it is least heated, viz., in the lungs rather than in the extremities.

Again, although gases may be absorbed by liquids, yet this absorption takes place in no great degree except at a very low temperature. The common process of making the soda-water, of the shops, ice being used to cool the water shows how necessary it is to make the water of the lowest possible tempe-

rature in order to force the gases to combine with it; and the vapid state of the beverage after it has become a little warm by standing in an open tumbler shows how averse the gases are to remaining absorbed by a fluid except in a state of extreme coldness. But this is not the state of the blood in the lungs. From these laws of chemical action, we may fairly infer that the oxygen does chemically combine with the carbon of the blood in the lungs; and that it is not absorbed in any considerable quantity by the blood.

SECTION VI.—THE RESPIRATORY FACULTY NOT PERFECT IN THE YOUNG OF ANIMALS AND IN INFANTS.

The reception of the theory which assumes respiration as the ultimate moving power of the circulation seems likely to meet a little obstruction from late experiments of Dr. Milne Edwards made on the young of certain animals. These experiments would seem designed to show that while respiration is the cause of animal heat, it is not the cause of circulation, since these animals have lived and their blood has circulated some twenty minutes after they were deprived of that function, although animal heat

failed. Dr. Turner in his "Elements of Chemistry" thus describes the experiments alluded to :—

"Some young animals, such as puppies and kittens, require so small a quantity of oxygen for supporting life, that they may be deprived of that gas altogether for twenty minutes without material injury ; and it is remarkable that so long as they possess this property, the temperature of their bodies sinks rapidly by free exposure to the air. But as they grow older they become able to maintain their own temperature, and at the same time their power to endure the privation of oxygen ceases. The same observation applies to young sparrows, and other birds which are naked when hatched ; while young partridges, which are both fledged and able to retain their own temperature at the periods of quitting the shell, die when deprived of oxygen as rapidly as an adult bird."

The first objection to the theory herein advocated arose in the mind of the writer from the fact that the animal circulation in its incipient state is undoubtedly carried on by the action of the heart ; and it was not until after much study and reflection that I became convinced that this objection did not materially affect the case. Lungs which are to fill so large a part of the adult body are then prepared but not used. But the moment they come into play, the organism of the

heart is changed, and respiration becomes necessary to life. So different are the two conditions that we cannot argue from one to the other. My observations on the phenomena exhibited by infancy and childhood led me, however, to believe that the lungs do not at once gain their functional power, but that the heart has, during infancy, more comparative force in carrying on the circulation than it has in childhood, and more in childhood than in adult years. The natural posture, especially in sleep, is significant of this fact. The nurse finds that the infant is quieted by hanging its head downwards. The child needs no pillow. The youth uses one to keep his head on a level with his body, but the adult generally requires his head to be raised some degrees higher. These are general facts which show a gradual diminution of the heart's comparative power from infancy to age. Boys at their sports often keep their heads downwards, in a manner which would be distressing to men. But the manner in which nurses wrap the heads of infants shows conclusively that their circulation differs from that of adult years. One case in point has happened within my knowledge, which goes conclusively to show that the human young, like those of other animals, can live without air in the lungs for a space of time, which would prove

fatal under like circumstances to an adult. An infant was carried in a sleigh three miles in a winter day closely wrapped in blankets and in the mother's cloak, and by mistake with its head downwards. The mother, when she found her infant's feet where she expected to see its head, supposed that she should find the child dead, but it was quietly sleeping. Had she examined she would probably have found that its temperature had fallen. A little longer exclusion from the air would doubtless have proved fatal to this child, as the lack of respiration did at length to the young animals upon which Dr. Edwards experimented, and the great law of nature would have taken its course, viz., that respiration, animal heat and circulation go on or stop together; together increase or diminish. As is the one so are the others.

SECTION VII.—TEN OBJECTIONS OF A MEDICAL GENTLEMAN REVIEWED.

It is now nearly six years since Dr. —— penned a series of objections to my theory. I intended replying to them, for I felt really obliged to him, for having treated me with the consideration manifested by his taking the pains to put his views into writing, and that in a manner entirely polite. But, subsequent-

ly, when I told him in conversation that I thought I could answer his objections, and he replied with some apparent acrimony, "then I can make more," I felt it a useless labor, since he was determined, at all events, to remain unconvinced.*

On this first occasion of my bringing this theory before the public, I shall present his objections entire, with a few remarks in answer. But I would not be unwilling that they should stand in my book without reply, for I am desirous to turn the keen scrutiny of candid inquiring minds to the subject of the work, and am confident that unless previous prejudice exists, the result will be, that, though some objections may arise, answers to them will spontaneously occur.

Here follows the first objection :

1. "In many cases of palpitation of the heart, the cause has been found to exist in that organ (on dissection), while the lungs have been perfectly sound and healthy. How can this happen, if the motive cause of the circulation be in the lungs ?"

Now, in reference to this first objection, let any

* Subsequently, as I have understood, this medical gentleman has alluded to the circumstance of my not having replied to him, regarding it as evidence that I could not defend my theory against his objections.

candid person read attentively the theory as laid down in the first chapter, the same as was in the hands of Dr. —— and he will see that a plain account of the difference between circulation and pulsation was there given; and palpitation is nothing more than irregular or excessive pulsation. This is fully discussed and made intelligible by the illustration of an india-rubber tube, by which it is shown that a pulsation, more or less violent, may be given to a fluid contained in an elastic tube, although it should be in a coil on a table where there was no current at all. And again: that by making such a tube the discharging conductor of a fluid and carrying it along an inclined plane, there would be a current without pulsation, and this would be more or less rapid, the force in this case being gravitation, as gravitation operates more or less freely, which would be determined by the inclination of the plane.

Another physician, Dr. N——, some three or four years ago, made much the same objection, saying that power could not pass from the lungs to affect the circulation, because the contraction of the left ventricle cut the stream. "You recollect," said I, "the beautiful rill* which comes rapidly down by the ra-

* Any person who has taste for fine scenery and is conversant with that around Troy, will at once recollect this fairy rill; for

vine-road. Take a piece of twelve inch board, and standing by this rill, put the end of the board into the little channel in a way to cut the stream; rest it a moment, then take it up, then put it down again, and so on alternately. Now, what will happen? Will a particle of the power of gravitation be lost by this cutting of the stream? No. But the onward little current will be for the instant dammed up against your board when it is down, but will flow the faster when you take it up; that is, there will be the current moving by the force of gravitation, as the blood from the lungs does by expansion, and this current will be pulsating, because the board will operate like the heart, as machinery to modify its flow. When the little stream is moving equally and gently you may cut it according to equal measures of time, 103 strokes in a minute, by your board, and then you have a regular pulse; or you may cut it 120 times in a minute, and then you may have a quick pulse; or you may hold the board in the stream some time, and then take it up, which would make a hard pulse;

ever flowing from its perennial spring, and in the driest seasons full, and its banks fresh and green, as it winds sometimes swiftly, sometimes slowly, by the road-side, and at the bottom of the deep and sombre ravine which extends along the southern base of Ida hill.

but the current all this time might be unaltered as to its velocity. But for a *palpitating* pulse you must find where there is a power of gravitation unusually strong, as by a rapid in the stream; here use the board briskly, and you may produce a *palpitating* pulse. The principle here developed applies to our theory. If the blood's current comes from the lungs and is cut by the momentary contraction of the heart's ventricle, it will in the same manner be checked for an instant, only to flow the faster and give a pulsation or palpitation, according to circumstances. This, then, which has been stated to be an objection, is, in fact, a constituent part of the theory itself.

We now state the second objection of Dr. ——.

"2. In cold-blooded animals, as the reptiles, there is not sufficient chemical action in the lungs to cause a degree of temperature above that of surrounding objects. Thus frogs and lizards have the temperature of the atmosphere in which they exist. Still their pulsations are regular, and their hearts, on being irritated, will continue to beat for hours after being removed from their bodies. In what manner can these facts be accounted for if the breathing apparatus causes the propulsion of the blood?"

This objection is, I think, founded in error. There

are, strictly speaking, no cold-blooded animals. Those which are comparatively so, have a languid circulation. But we nowhere attempt to show that the heart has not power, but everywhere maintain the contrary. There is, however, too much difference between the circulation in a human being and that in a fish or a reptile, to enable us to reason from the one case to the other.

In confirmation of our views we quote the following from Liebig's "Animal Chemistry;"

"It is obvious that the amount of heat liberated must increase or diminish with the quantity of oxygen introduced in equal times by respiration. Those animals which respire frequently, and consequently consume much oxygen, possess a higher temperature than others, which, with a body of equal size to be heated, take into the system less oxygen. The temperature of a child (102°) is higher than that of an adult (99½°). That of birds (104° to 105°) is higher than that of quadrupeds (98½° to 100°), or than of fishes or amphibia, whose proper temperature is from 2° 7′ to 3° 6′ higher than that of the medium in which they live. *All animals, strictly speaking, are warm-blooded;* but in those only which possess lungs is the temperature of the body quite independent of the surrounding medium."

Objection Third.—"In hot-blooded animals, as the mammalia, is there a sufficient difference between the temperature of the lungs and the other parts of the system, to cause the blood to flow from the former to the latter parts?"

Before any one can tell what a sufficient difference is, it must be stated what would be the amount required. Dr. —— is referred to the remarks on Dr. W. F. Edwards's letter, where the subject of definite measures is treated of. If we prove, as we think we have most conclusively done, that expansion is the principal motive power, then questions concerning quantity of force have no significance, except to show what with this force will be the velocity. The velocity does not regulate the force, but the force the velocity.

Objection Fourth.—"Men engaged as divers in the pearl fishery finally obtain the power of suspending respiration for two, three, or even in some cases, five minutes, and still their pulsations continue, though, it is confessed, very imperfectly, since their faces become livid from want of chemical action in the lungs. In such cases would not pulsation cease entirely did it depend on the action of the lungs?"

But who has said that pulsation does depend on the lungs? or that pulsation is circulation? As to

the manner in which respiration and pulsation move on together, I expressed my opinion in the first chapter by saying that it was like the voice of the musician and his accompanying instrument, they were not in unison, but in harmony. The best remarks on the facts of this harmony varying, yet as by a rule, which I have anywhere met, are contained in an "Essay on the Relation between the Respiratory and Circulating Functions," by Dr. Charles Hooker, of New Haven, from which the following extracts are made:

"Definite ratio is observable between the frequency of the respiration and of the pulse. As a general rule, this ratio may be stated as *one to four and a half*—that is, in a healthy, well-formed adult, when the pulse is seventy in a minute, the number of respirations is about fifteen or sixteen; while, if the pulse is naturally more or less than seventy, there is a proportionate frequency of the respiration." Dr. Hooker founds his opinion on extensive observation. "Authors," he remarks, "are not agreed in regard to the natural ratio between the respiration and the pulse. This ratio is stated by Haller to be as one to three or four; by Graves as one to four," &c. Dr. Hooker closes the paragraph by this important and doubtless correct rule: "Any circumstance which prevents a full quantity of air from being received

into the lungs with each inspiration, necessarily calls for more frequent respiration. As a general rule, *if the respiration is deficient in fullness, the deficiency is compensated for by increased frequency.*"

As for the fact alleged in this fourth objection, we consider that it makes against the objector, and in favor of our theory. It proves not that men can live and their blood circulate without respiration, but that they cannot.

Five minutes, it seems, is the utmost limit, and because by a process of special training, men can acquire the power of *living five minutes* without respiration, surely then we are to conclude that breathing is not of any great consequence after all! One chemist, Dr. Brodie I think, supposed a race of men might be so far improved in this particular that they could dispense with breathing perhaps for hours. We think not. When the circulation stops, men must die. But why does death follow when breathing ceases? Because some may say the blood is black which the heart sends, and the heart will not continue to circulate black blood. Now that is a mistake. The heart is indifferent whether the blood is red or black. Indeed, the right side of the heart always carries black blood, and the left carries black blood in some fevers, and on other occasions. There-

fore the circulation does not stop on this account. Were there no other reason the heart would labor on much longer than it does, and carry round black blood. But the heart stops when, the last expansive power stopping at the lungs, no more blood is thrown from the lungs, to stimulate the heart's action. It has then nothing to circulate. This is shown to be true by the fact of artificial respiration in cases of drowning, &c., setting into renewed motion a heart, which, not stimulated, has ceased to beat.

Objection Fifth.—"If it be admitted that the temperature of the lungs be so much greater than the other parts of the system, as to cause the blood to flow from them, ought not the stream to be continued rather than pulsatory?"

On account of the heart's contractions it ought to be pulsatory, and on account of the expansive power generated at the lungs, it ought to be continued, and the facts agree. The blood's current is, as it passes through the arteries, both continued and pulsatory.

Objection Sixth.—"If the blood, in common with other fluids, expands by heat, of which there is no doubt, then an equal weight of the former when in the lungs, would possess a larger volume than when in any other part of the system. Now, the heat of the lungs, from whatever cause it may arise,

is the same in any given animal, or in other terms, is not subject to sudden variations. The lungs, then, are always full of blood at a higher temperature than the other portions of the system, and this, according to the theory, causes it to flow from these organs to the other parts of the body. But the inquiry now arises, what cause is there which impels the circulating fluid back to the lungs, since in them is seated the perpetual cause of its outward or forward motion ?"

This question refers to the venous circulation, and we think has been fully answered in our remarks on that subject. Large buildings are now heated by circulating warm water, and precisely the same question might be put, as to the manner in which the colder fluid comes back to have its heat renewed.

Objections Seventh and Eighth.—"In many instances the lungs have been almost entirely destroyed by disease; and in others their delicate tissues have been found so deranged as not to perform one half or one third their usual healthy office, and yet the action of the pulse has continued regular and unaltered." (That is an affair of the heart, not of the lungs.) Did the motion of the blood depend on the lungs, would not some derangement of this motion have been perceptible under such circum-

stances? A friend of mine, during the late war, was shot through the left lung, and still the circulation of the blood continued as usual, and although he bled profusely by the mouth, he recovered, and is well at this day. Now, were the lungs the seat of life, or, in other words, the origin of the circulation, could this have happened, and would not death have been the inevitable consequence of such an accident?

On this subject let Dr. Hooker speak. "If, by disease, a portion of lung is rendered unfit for respiration, the remaining healthy portion, having the whole office of aeration to perform, must act with increased frequency, in order duly to arterialize the blood (and to circulate it also). If for instance, only one half of the lungs is fit for respiration, the frequency must be doubled." This gentleman mentioned, must have been obliged to breathe very rapidly to gain oxygen enough to warm and circulate his blood. If our Heavenly Father had not provided for such emergencies, by giving several different lobes to the lungs, death would unquestionably follow.

Objection Ninth.—"The trunks of all the blood-vessels have a common origin at the heart, to which they are united, and in which they insensibly lose themselves; so that, with respect to the arteries it is

difficult to say, at what exact point those vessels end and the heart begins, since in common with the heart, they possess a muscular origin. The heart itself, with these muscular arteries, forms, as a whole, the most powerful muscle in the human system And hence it is, as has heretofore been supposed, that we are to account for the surprising force with which the circulating fluid is impelled through distant vessels. This whole apparatus is formed with infinite care and surprising skill, apparently for the very purpose of acting with great power on the mass of blood which it encloses. *This being the acknowledged fact in view of all anatomists*, the question naturally arises, for what purpose is this peculiar adaptation designed if the lungs are the motive power of the circulation ?"

Of all anatomists, perhaps John Bell has the most admirers. Honest John Bell, peace to his manes ! Let us hear him on the subject of this adaptation of the heart, which our correspondent says is so clear to the view of *all anatomists*.

" The heart," says John Bell, " is fixed by nothing but its great vessels as they run up towards the neck, or are connected with the spine ; but how slight this hold is, how much the heart must be

moved, and these vessels endangered, by shocks and falls, it is AWFUL to think."

Again he says, "the posture of the human heart is very singular; and is so distorted, that no one part has that relation to another which we should beforehand expect. In the general system, the human heart is placed nearly in the centre, but not for those reasons which Dionis has assigned; it is not in order that by being in the centre it may feel less the difficulty of driving the blood to any particular limb or part of the body; *it is the place of the lungs that regulates the posture of the heart, and wherever they are, it is.*"

And in another place he remarks, "its posture is difficult for us to conceive, no one part having that relation to any other part, which we should beforehand suppose."

Dr. Arnott says, "it is a remark respecting the pulse, appearing to the author worthy of deep consideration, that if the purposes of the heart and arteries were merely the propulsion and conveyance of the blood, their structure and action would form most signal deviations from the ascertained rules of fitness in mechanics."

"Now, one use of the pulsation of the heart probably is, by the *agitation* and *churning* which the

blood suffers in passing through it, to keep in complete mixture, all the heterogeneous parts of the blood, and which so readily separate when left to repose. But this cannot be the only use, for the object might have been more simply attained; and we may conclude, *that the phenomenon has relation to some important law of life still hidden from us.*"

"We see," says Bichât (under the head of Remarks upon the Pulse), "by the different views that I have presented, that almost all authors have described in an inaccurate manner the motion of the blood, and what loose ideas they have had of it, experiments have only served to confuse them; it is a work that requires to be entirely done again."

For the opinion of Dr. Roget on the same subject, see chapter two.

Objection Tenth—First Part.—"It being kept in the mind that all the blood-vessels begin at the heart, let us for a moment trace the circulation and observe the effect of supposing the moving power to be the lungs. From the right ventricle the blood is thrown by the pulmonary arteries to the lungs, there to undergo the chemical change by means of the respiration. The fluid is then returned to the left ventricle by the pulmonary veins in a continued stream. From the left ventricle it is sent to all parts of the

system by the aorta, and is again returned to the right ventricle by the vena cava, and then again to the lungs by the pulmonary arteries, and so on in a continued circulation. Now suppose we reverse this order [but why? we nowhere speak of reversing the blood's current], and begin with the lungs as the source of motion, and imagine that there is a force there (no matter how obtained) sufficient for the purpose in question. Then in the first place, this force must be exerted on the capillary vessels of the lungs [and if it is not, what force is exerted?—some force must be, or the blood would stagnate], a tissue so exceedingly fine and delicate as to allow the oxygen of the atmosphere to act on the carbon of the blood, through the substance of which they are composed. Would these vessels withstand a pressure sufficient to propel the blood to distant parts of the system?"

The chemical force supposed of a fluid going from warm to warmer is so gentle that ordinarily it would not derange a spider's web. But when respiration is violent, and great quantities of blood are thrown upon the lungs, lesions of those tissues do occur. They can withstand the action of heat better than any other part of the whole body. Dr. Arnott says "a healthy man can breathe with impunity air that is considerably hotter than boiling water."

Second Part of the Tenth Objection.—"The vessels through which the blood is impelled from the lungs, are, and must of necessity be, arterial, otherwise there would be no pulsation, for the veins never pulsate. The pulmonary arteries, therefore, are these vessels, since none other of this class reach the lungs. But how can this be, since there are valves which prevent the motion of the blood in that direction, and if this were not the case, in what manner could the blood thus reaching the heart be sent to the other parts of the system? But suppose the blood to be impelled from the lungs by the pulmonary veins into the left ventricle, how then could it pass by the aorta to the other parts of the system, except by the contraction of the heart?"

Here we are in a denser fog than ever, on account of confounding pulsation with circulation. The veins, it is true, do not pulsate, but nevertheless they *circulate* the blood. We are told that "the vessels through which the blood must be impelled from the lungs must be arteries or there would be *no pulsation*." What then? There may be and doubtless is, from the lungs to the heart a rapid *circulation*, and this is all we contend for. But the name "pulmonary veins" is given to this part of the blood's course, and very absurdly too, because they carry

arterial blood, and are a part of the great arterial system. On this head I have quoted Bichât, and introduced a figure explanatory (see page 15), which will give an intelligible though imperfect idea of a subject which is as difficult to comprehend as the relative position of the parts of the solar system. But to return to the objection. We are told that if the expansive theory is true, the blood must go from the lungs (on account of pulsation) in arteries; and as there are none but the pulmonary arteries, it must go there; but there it cannot go on account of the valves. This pulmonary artery carries venous blood and we think should be called a vein, as being a part of the great venous system. (See quotation from Bechât, pages 28, 29.) Now we have clearly stated many times that the blood's course must be from the lungs to the left ventricle, as the valves direct; that it is not pulsation but circulation which comes from the expansive force, and that pulsation is imparted to the current by the heart's beat; and that this beat is also in a degree, available as a circulating force.

SECTION VIII.—THE BALANCE OF TEMPERATURE FOR THE HUMAN BODY.*

When objections to this theory have been made, they have set me upon new trains of thought respecting it, by which I have been confirmed in its truth. Professor —— delivered a lecture in Troy, in which he had much to say upon the sacred claims of truth, and the readiness with which it should be received, let it come from what quarter it would. Here, thought I, is a man who will examine this theory candidly, notwithstanding a woman proposes it. Accordingly I laid it before him; but he seemed filled with what he doubtless considered a righteous indignation. He made many objections, which I readily answered. At length he asked me what, on my principles, would ensue in case the exterior of the body became equally heated with the interior? I told him I thought the subject would not live long; but really I had not considered just this case, and

* This section, as it now stands, was written some five years ago. Although this subject is often alluded to in other parts of the work, this view contains additional facts, and a logical argument for the truth of the theory.

should like to take a little time to reflect before I answered him. He, however, immediately took his leave, with an exhortation, the spirit of which was little short of this, that ignorant people should beware of what they advanced in presence of the wise.

This incident led me to observations which have tended to confirm my belief; for if logical inferences from a physical principle, are found to be conformable to facts, the presumption is that the principle is true.

1. Let the hypothetical principle in this case be, that the change from colder to warmer, and the reverse, which the blood undergoes, causes it to circulate If this be a true principle then the greater the change the more rapid will be the circulation, and the reverse. It is a fact which none will deny that the greatest range of difference between maximum and minimum temperature produces the most rapid circulation, and the reverse.

2. If Infinite Wisdom designed the circulation to be carried on in this manner provision would have been made for such a due degree of difference between the heat to be carried off at the surface and that to be received at the lungs, as will produce, under ordinary circumstances, the balance proper for health. The question here is, has this been done? It

has. The important fact at once strikes us, that a cold, dense air, while it carries off more heat from the surface, supplies more of the heating principle to the lungs; and a warm air, on the contrary, carries off less externally, and supplies less internally; keeping the mean temperature the same; making, at the same time, as health requires, a brisker flow of the blood in cold climates than in warm.

3. Reasoning from uniform analogy, provision will also be made in nature for any such deviation from the circumstances which produce the normal balance, as are likely to occur. Such provision is made. When the climate, of itself, would produce an undue coldness in the animal system, the external surface in the lower orders of animals is defended by furs, wools, &c., which are finer and softer as the climate is colder, and even the same animal experiences this change if he migrates to a more severe region. Man is endued with reason to provide clothing according to the climate he inhabits, and to build dwellings to exclude the cold air; and to him is given what Nature prudently denies to lower animals—the use of fire. Man can regulate the temperature of his rooms according to the season. And to all animals is given an instinct no less remarkable than that of hunger, by which they take necessary food, viz., a

feeling of uncomfortable coldness, which impels them to seek instantly a covering or a shelter from a degree of cold which would endanger the necessary balance. On the other hand, Nature has made provision against injury from an undue degree of heat, by perspiration, which, though constant in degree, is most remarkable when considered under the head of its varying to suit the demand for a cooling agent, being kept in a state where moisture easily exudes; this moisture evaporates in the warm air, which is its most common cause. The extra quantity of heat is carried off, and the proper balance restored. This fact would have furnished a reply to the question of the Professor. For if a case should occur where by exercise or otherwise a healthy person should become so heated that there was scarcely any difference between internal and external temperature, immediate copious perspiration would ensue, or death would supervene. The instinct we have spoken of leads the lower animals, when heat is excessive, to seek cool shades and places where water is evaporating, and to wade in brooks where their extremities are cooled. Man throws off a portion of his clothing, bathes his body, especially his hands and face, from which the blood has a quick return to the lungs, and he closes his shutters against the noon-day heat:

universally, the animal creation are indisposed to exercise when oppressed with heat. In sultry climates artificial evaporation is added to natural, and fountains are made to play in human dwellings. The race who are the natural inhabitants of the torrid zone have a skin which does not so freely imbibe external heat, and whose pores more readily admit of copious perspiration.

4. If, however, by extraordinary and untoward circumstances, the proper balance is destroyed, disease would ensue, and if the balance could not be restored, death.

I asked an eminent physician, after the question of Professor ——, what would be the consequence of immersing a man in a bath of a temperature equal to that of the blood in the lungs, giving him, however, a chance to breathe. He said, fainting in the first place, and death in the second. This was consonant to the reply I made to Professor ——. Dr. Andrew Combe somewhere states, that if man were cased in a material which wholly excluded the air from his skin, it would cause death; on the other hand, it is indisputable that a degree of external coldness which overcomes the internal heat of the animal system produces disease, and eventually death.

5. As the air is the grand medium of keeping up this balance by imparting, at the same time, internal heat and external coldness, if air is entirely withheld, the alternation from colder to warmer, which on our theory produces the main force which keeps the blood in motion, must utterly fail, and partially, if it is withheld in part. This is indisputable in point of fact. Every one knows that if air is withheld, circulation stops; if imperfectly supplied, circulation is imperfect in the same degree.

6. But on our principles there must not only be air, but the lungs must receive it and perform upon it the healthy vital function; by means of which, the calorific principle, which we suppose none will deny to be evolved by the agency of oxygen, shall pass into the blood. If, therefore, that vital function is deranged, the balance spoken of will be deranged, notwithstanding air at the same time may be duly supplied. And this vital function may be deranged either by some irritating cause, which makes the lungs play too rapidly, and thus disengage too much heat; or on the other hand, by a want of nervous energy, the breathing may either become too slow, or though performed, may, from nervous disease, as Dr. Hooker has ably shown, fail of efficiency to perform its function. Dr. Todd said in his last illness, "I

breathe, but my breathing does me no good." Again: the lungs may be wasted by disease, and though the remaining portion play more rapidly, the utter derangement of the proper balance will eventually take place, if such wasting disease be not arrested.

7. If we neglect to avail ourselves of the provisions which nature has made or indicated, and which it is proper we should resort to when circumstances occur, without which the proper balance between internal heat and external coldness would take place, then disease will ensue. If man either will not or cannot obey the warning given by the feeling of uncomfortable or distressful coldness or heat, and use his reason accordingly to change his clothing or his position, then the proper balance will be destroyed, and disease or death will be the consequence.

Thus, we see, that reasoning from the assumed hypothesis that the blood's change of temperature from warmer to colder and its reverse causes it to circulate, that every logical inference is fully sustained by a great and important range of facts, the experience of the whole animal creation, not merely *experiments* on a few young animals; we are, therefore, logically entitled to the conclusion, that the hypothesis assumed is itself true.

CHAPTER V.

PATHOLOGY, FUNCTIONS OF THE LIVER, &c.

SECTION I.—FEVERS CAUSED BY MIASMS, ETC., WHICH AFFECT NOT THE HEART, BUT THE LUNGS.

We should not do justice to our argument, should we wholly neglect to show the strong proofs which the expansive theory derives from pathology. But we approach the subject with humility, aware how much greater than our own is the knowledge of others respecting the diseases of the human frame. But God, in natural as well as in spiritual things, sometimes choses to reveal himself by "the weak things of the world," "that no flesh should glory in his presence;" and that "he who glories should glory in the Lord."

We shall, on this subject, chiefly confine ourselves to two points, viz., fevers and diseases of the heart.

1. *Fevers.*—In Dr. Copland's Dictionary of Practical Medicine.* edited by Dr. Lee, Part VIII., p.

* The work is not yet fully published.

1053, we find the subject of fevers largely discussed. Dr. Copland, though embarrassed with the difficulty which his predecessors have felt, of giving a definition to a disease so varied in its form, yet shows that fevers are invariably a derangement of the circulation. But Dr. Copland hesitates not to assign the exciting causes of fevers. After enumerating these at large, he sums up by saying, that "*infectious effluvia, miasms, &c., may be said to be the specific, efficient or essential agents, or exciting causes of fever.*"

The circulation must be as its moving cause. If this is principally impulse communicated by the heart, then these exciting causes of derangement must first affect the heart, before they can influence the circulation. But the heart lies wrapped in the pericardium, totally excluded from the air, or aught which it contains. Besides, the air is not the medium of excitability to its action, but when the heart, just taken from a living body, is exposed to the air, its action ceases. In this state, warmth and fluidity may excite it to renewed exertions. These, not air, are then the exciting agents of its action. Since, then, the heart can in no way be directly affected by the air or any miasma which it may contain, and since derangement of the circulation comes

from unhealthy substances floating in the air, therefore, the heart's action is not the principal motive power which carries on the circulation, but some other agent is, which is susceptible of being deranged by the effluvia and miasma which the air conveys.

Now, the great channel through which the air affects the circulation passes the membranes of the lungs. The blood is then exposed to its action, over a surface equal to about seven times the whole surface of the human body. And it is known that all healthy circulation comes from a proper supply of wholesome atmospheric air here received. And it is perfectly apparent that a vitiated atmosphere must, and does, produce disease of the circulation through this channel. For, if oxygen is not supplied in proper quantities the deleterious carbon will not be burned, animal heat will fail, and a low circulation must supervene. Again: if an air, vitiated by imperceptible particles of some poisonous substance, enters the lungs, this organ may inflame, and thus its vital action become increased. In this state the lungs will work rapidly, inhale undue quantities of oxygen, and so much heat will be evolved, as to destroy the balance which we have seen that nature has fixed between the maximum heat at the vitals, and the minimum at the extremities; and although

the skin may pour forth its perspiration, this great heat at the vitals continuing, life may thus become extinct. Again: we have shown how perspiration at the skin is a safety valve to keep up this balance; and if that is stopped, the ordinary heat excited at the lungs might destroy the balance and produce that equal degree of caloric throughout the whole system, which would annihilate the power of expansion. To sum up this argument, the expansive power generated at the lungs by respiration is susceptible of such derangements from the influence of miasms and effluvia, as are the acknowledged causes of fevers, and it is the only conceivable motive power in the circulating system which is thus susceptible; therefore it is the principal motive power.

SECTION II.—DISEASES OF THE HEART OFTEN DESTROY THAT ORGAN SOME TIME BEFORE DEATH—POSITION IN THIS CASE MUST BE UPRIGHT.

Again: in diseases of the heart the circulation goes on, and the patient lives after the heart's substance has become so far decomposed that on post-mortem examination the finger can penetrate its thickest walls. Two such instances occurring in men of

large muscular frames, are now in my mind. One was related to me by Dr. Smith, of Newark, New Jersey, and was the case of Dr. Griffin, his father-in-law, the former President of Williams' College; the other was that of Mr. Wilson, of this city, related to me by his physician, Dr. Robbins. In both these cases the patients lived until the substance of the heart was decomposed. But the trunk in diseases of the heart must be kept upright, or nearly so. In a case mentioned by Dr. Hope in his work on "Diseases of the Heart," now before me, he says, the patient "falling from his night-chair immediately expired." In another place Dr. Hope thus quotes from Corvisart: "Carditis ultimately converts the muscular part of the heart into a soft and pale substance, and in other cases it is in part destroyed," and in such cases on post-mortem examination, "the walls of the heart tear with the least effort, and strong pressure is not necessary to reduce them to pulp." Now these states of the heart no one will suppose come on at death, but were gradually approaching during life. But life presupposes circulation, which must have gone on with a heart thus enfeebled, and in fact destroyed. And who can suppose, after a moment's reflection, that such a heart could afford an impulse sufficient to move the blood? But the blood

does move, and therefore some other agent moves it, and an agent too which requires that when the heart is diseased, the trunk should be kept upright. Just such an agent is the expansive power, for which we contend, and no other motive power known to man does, of itself, operate with an upward force. This, then, must be the power which, when the heart fails, carries on the circulation.

Dr. Stamatiades, when an attendant in a hospital, had under his observation, as he related to me, a case in which a patient lived twenty-four hours after any movement of the heart by pulse or otherwise was perceptible. "He was, of course," I remarked, "kept with his trunk upright." "Yes," said the doctor, "and died immediately in consequence of falling from that position." That death finally supervenes on excessive derangement of the heart, is no valid objection to our argument—for when the heart's action becomes deranged, the course of the blood may be checked, and the action of the lungs diseased by sometimes wanting a due quantity of blood, their proper stimulus, and by sometimes being left engorged by obstructions in the passage which should carry them off. And then nature requires rest, and the lungs can have little when the heart is diseased. But diseases of the heart are, as remarked in the first

chapter, often caused by the morbid inaction of the lungs. When they fail, the heart's action becomes instinctively more violent, a provision by which nature gives to the animal frame a stronger hold on life.

In fainting, or syncope, Dr. Copeland says that "the pulse is unaltered or increased, for in some cases he found it so strong as to prescribe depletion, but the respiratory organs are nearly abolished." The first remedy prescribed, and in some cases the only one, is immediately placing the patient in a recumbent posture. What other theory than the one we advocate could afford a rationale for this process? But this theory would suggest that when the respiratory action fails, and the heart's force is for the moment to be depended on, that the circulatory system should then be laid recumbent, as in that position this force works to the best advantage. And the common expedient of throwing cold water in the face of a fainting person, derives its efficiency in restoring respiration from that instinctive gasping and violent breathing by which Nature obliges us to guard the healthful balance of internal heat against sudden external coldness.

SECTION III.—THE LIVER.

We have said that we regard the circulation of the liver as peculiar and functional. In my earliest researches into the phenomena of the circulation, the liver was the grand enigma. For what purpose has the wise Creator inserted that enormous inert mass within the body, and how, on any hypothesis, is its circulation maintained? Is it formed solely to secrete bile? But from the place where the biliary duct discharges itself, I found reason to believe, and the subsequent researches of Liebig have proved it, that the bile is chiefly excrementitious; and that it is conducted away from the liver to cleanse and purify its substance. This was peculiarly impressed upon my mind by a case of jaundice, in which the patient became of a saffron color in one night. His entire surface, the whites of his eyes, and even his nails, were thus suddenly changed from the natural hue to yellow. This was doubtless caused by the stoppage of the biliary duct, and the consequent transmission of the bile to every part of the system.

Again: another subject pressed upon my mind, how in cases of an abstinence from food (drink being supplied), could circulation be kept up ten,

twenty, and sometimes even forty days. The veins and arteries must be filled, or the circulation ceases. The waste must go on—carbon must be supplied for the oxygen to burn at the lungs, or respiration must cease. Daily showers cannot be depended on to keep the pipes of the aqueduct full, there must be a reservoir, and the larger that is the less the danger from drought. Then, it occurred to me, whether the liver might not be this reservoir in the animal system, and I learned from the two Bells and others, that the ancients long held a similar opinion.* But, does the liver actually expand when nature, for an important object, has to store away for months some two or three quarts of blood? That it does, there is ocular demonstration. Does this additional volume disappear, when the blood is used for the purpose for which infinite wisdom reserves it? It most assuredly does. But if the liver distends, it must press upon the stomach and may disturb its

* "The ancients," says Sir Charles Bell, "made the liver the supreme director of the animal system. They supposed they could trace the nutritious fluids of the intestines through the mesenteric veins into the heart and the liver, and that there it was converted into blood. From the liver to the right side of the heart, they found the cava hepatica carrying the blood formed in the liver to the centre of the system; and through the veins they supposed the blood to be carried to the remote parts of the body."

functions. That disturbance does actually occur. Let physiologists follow up this train and they will find in it proof added to that adduced, which, if no countervailing argument can be found, would prove conclusively that the use of the liver is to furnish a capacious reservoir to the blood; by which to give the animal and the race a hold on life, which they could not otherwise have.

Let us, then, with this clue, look to the structure of the liver. If nature designed such a reservoir, it could not be filled with blood in a liquid state, for the supposition of a pool of stagnant blood within the system is wholly inadmissible. To construct then, an organ, with just solidity enough to gain life from the nerves and be nourished by the healthy blood, while it should contain within its peculiar structure the reserved supply for the circulatory system, is a work worthy of infinite wisdom. And add to this great object still another, viz., the farther preparation of the aliment received at the stomach, and of the fat which must go into the circulation and be consumed, before death can supervene from starvation, concocting from, and discharging their deleterious properties through the biliary duct. Allowing these to be the functions of the liver, and uses are found for that organ, to which its situation and its

structure signally agree, and which are adequate to its comparative dimensions. This view of the functions of the liver is confirmed by other facts than those already adduced. Of these, is the resemblance of the liver to the crassamentum of the blood, which is matter of common observation. Heat affects it in the same manner, and its taste when thus affected is the same. Less heat prepares the liver for food than is required by any other solid part of the body; nay, Mr. Murray, in his travels among the Pawnees, assures us that the Indians take it warm from the expiring buffalo, and find it as nutritive, and it imparts almost as much fluid as fresh milk, and if my recollection serves me, he partook on one occasion himself of the banquet. Again: the Indians, it is well known, are in the ordinary custom of making at one time, a meal which serves them for days. But they press with their belts the region of the liver when the food has passed the stomach, and then suffer no inconvenience from a few days' or even a week's abstinence, for they continue to draw and close the belt.

If such be allowed as the uses of the liver, its position as taking the first heat of radiation from the lungs, confirms the view elsewhere taken, that what the blood collected in the veins needs, to fit it for

circulation, is not oxygen but caloric; and that it is for the purpose of supplying fuel at the lungs that carbon is carried there, and oxygen there furnished by respiration. Without this view of the functions of the liver our theory of the motive powers might be taxed to account for phenomena arising from the functional action of that organ. For if its functions be those supposed, the great circulation which issues at the vena portæ, must be a constant process of composition and decomposition, and the blood which the liver prepares for the circulation will pass into it when prepared by the vital energies of the organ. But if these become deranged by an action either too feeble or too vigorous for the standard of health, then the circulation will become deranged from other causes than those which concern the motive powers. Much the same may be said of the vital functions of the stomach. Their derangement must cause disorders of the circulation. Again: as every function depends for life upon the nerves, the course of the circulation will be subject to derangement from their influence, whenever their action becomes morbid. The brain acts on the viscera. Grief stifles the respiration and weighs upon the heart. Modest shame sends upward from the lungs, like a sudden flash, the crimson which mantles the cheek. And rough anger

has been said of old, and I believe it true, moves the languid liver and "stirs up the bile." It may thus, by sending additions of blood into the circulation, give vigor to the arm which, perchance, needs unwonted energy for defence from threatened injury. The color of the face in violent anger resembles in degree that of the liver, and warns the aggressor to beware.

But these remarks on the liver are thrown in incidentally. I do not rest my theory of the motive powers on proving that the uses of this organ are what I have suggested.

SECTION IV.—ON SLEEP.*

All the physical changes which take place in the system when it passes from wakefulness to sleep, we do not pretend to understand, but the theory proposed affords some light on this obscure subject, and there is a change from infancy to old age, which agrees with our solution as far as it goes. It is thus, when we lie down we place the head in a position where, according to our theory, the upward-mounting of the warmer particles of the blood must be

* I find this article among my papers, it having been written three or four years since. Its facts may not be uninteresting.

checked (the heart then taking up a more resolute beat to carry on the circulation). The flow of blood to the brain is thus lessened, and a tendency to mental inaction consequently produced. The unpillowed infant sleeps sounder and more than the youth whose head is slightly raised, and he more than his parents, whose heads must be made higher, or they are distressed for breath. The little children of a family are put early to bed, and sleep soundly all night. The young folks have their evening pastime, but they love their bed in the morning, while their parents are up with the sun, and perhaps their aged grandparents, unable to sleep, have lighted their fires and candles before the dawn of day. Now, if, as we believe, any common observer will agree that with this change of the quantity of sleep necessary, there is conjoined the tendency to raise the head more and more, and if, at the same time, the need of pure air to breathe is more and more experienced, why should we doubt the philosophical connection of these parts, especially as they naturally proceed from a theory which we have antecedent reasons for believing, and which, by the way, they serve to confirm.

When we lie down at night we should not, if possible, allow our minds to be occupied with such exciting subjects that we cannot go to sleep soon, for

otherwise we may chance to pass hours of restlessness. This may happen from the fact that the blood, when it acquires its momentum in the horizontal posture of the body, supplies the head more freely than when we first lie down. As a proof of this, we may often find that if we rise when we are wakeful, and sit up awhile, still more if we stand or walk, and then lie down again, we are more likely to fall asleep than if we continue in a horizontal posture. If our reasoning is correct, the heart and lungs, though each must constantly play (especially the lungs) or life cannot, in any position, be long retained, yet each have their seasons of comparative rest, the heart during the day, and the lungs at night. The heart beats oftener in children, and the lungs work harder, especially in sleep, with the aged. Children do not snore.

Does the blood flow, during sleep, with the same rapidity as in our wakeful hours? It is not, we conceive, easy to determine, for we believe that the heart often labors hard, making a strong pulse to carry on a slow circulation. But we need more covering, and can less afford to lose heat in that state. Young persons who are growing fast require much sleep, and there are other indications that accretions to the solid parts of the body are made from the blood

during sleep. Now it is the slow and not the rapid current that deposits its more solid parts. This would lead us to believe in the slower movement of the blood during sleep. The inactivity of the brain also indicates it. Our theory would antecedently lead us to believe it—and if such is the fact, it confirms the theory.

Sleep, it is known, has a refreshing effect. "We must eat or we must sleep," say the Indians. Does not the liver, at the moment when sleep occurs, send forth a portion of its thicker and heavier blood, which is more fit to repair the waste of the solid and sluggish parts of the body than to give action to the brain? This hypothesis has been suggested by some phenomena occurring at the time of the falling asleep of a person slightly afflicted with heart-disease. Strength in the solid parts of the frame is renewed by sleep.

CHAPTER VI.

THE THEORY OF EXPANSION TESTED BY ITS UTILITY.

SECTION I.—EFFECTS CAN ONLY BE CONTROLLED WHEN CAUSES ARE CONTROLLABLE, ETC.

The theory now first offered to public consideration is worthy of attention, because, if true, it must be of great utility both in preserving health and in restoring it when impaired. That the subject of the circulation of the blood is of the highest moment, both to physiology and pathology, is attested by the universal precedence which is given to Harvey's discovery over any other in the annals of those sciences. But since it is only by modifying causes that effects can be controlled, that great discovery of which the English nation is justly proud, cannot be made fully available if there exists a mistake as to the efficient cause which produces circulation.

Again: if expansive force generated by respiration shall be found a true motive power, important improvements cannot but result to the sciences both

of health and disease; because respiration is so much more under control than is the heart's action, which has heretofore been considered the sole cause of the blood's current. The heart is sealed against direct approaches. No man can by his *direct* volition make his heart beat quicker or slower. But there are nerves of voluntary, as well as of involuntary respiration; and we can change the air we breathe by a change of climate, or by altering our habits of more or less confinement at home, and by keeping a higher or lower temperature in our houses.

We have said, that no one can by direct volition make his heart beat quicker or slower; but by an *indirect* volition operating on respiration, we can even affect the heart's motion. Dr. Marcey, of Hartford, made some nice experiments by which he became fully convinced of the truth of this theory, being assisted in them by his students. As the theory teaches that both animal heat and circulation depend on respiration, the experiment was made by a rapid voluntary breathing of pure atmospheric air for some moments with quick and deep respirations: after some little time it was found by the thermometer that the temperature rose, and by counting, that the pulse quickened. The contrary process of re-

tarding respiration was then tried, and the contrary effect produced. The temperature fell, and the heart's beat was less frequent. Dr. Arnott says, "late physiological investigations have shown that the action of the heart is dependent on the breathing, but not on the brain, except as the cause of breathing—for that respiration kept up artificially, will preserve the circulation and the life, for a considerable time after the brain has altogether ceased to act, or even has been removed from the body."

If what has been already suggested on the fevers and diseases of the heart be correct, then it clearly appears that this theory, if true, is highly important as it respects those maladies.

The opinion that the heart's action alone, and not the vital functions of the lungs, carries on the circulation, has caused disastrous consequences by misleading the common mind into a disproportionate anxiety respecting the diseases of these organs. Hence, symptoms of disease of the heart are magnified by distressing apprehensions which are calculated to heighten all those symptoms; while the patient perceives not in due time, that the strengthening of his lungs has any significancy in cases of heart disease; or that it is necessary to his relief, that he should breathe a pure air, and keep,

especially during sleep, such a position as shall give the lungs an opportunity of relieving the heart.

On the contrary, complaints of the lungs do not fix early attention as they would if it were believed that from the lungs comes the first and principal force of the circulation, and in a manner as by fire in a receiver, the lesions of which, by the very quality that fits it for its office, as well as by its indispensable constant use, are more difficult to heal than those of any other organ. Hence, many a one has trifled with the beginning of diseases in the lungs, until he has waked from his thoughtlessness to find himself hastening to the grave with incurable consumption. Laennec remarks, that of the multitude of cases of phthisis which came under his observation, in the *majority of instances the cause of the disease was unknown.* One third of the patients ascribed the first symptoms to alternations of heat and cold, to which their avocations exposed them; to draughts; to immersion of the feet in cold water; to drinking cold water when perspiring.

SECTION II.—ILL DIRECTED CAREFULNESS IMPAIRS HEALTH.

Again: this theory may teach parents how they often expose their children to disease, by the very means which they take to prevent exposure; nay, how many do so in their own persons? If a friend advises us to take care of ourselves, we naturally understand that he means we shall keep in-doors in heated rooms, and refrain from energetic exercise. But this theory teaches us, that the vigor of the circulation must be in proportion to the difference between the temperature at the vitals and that at the extremities; and that a small difference must give a languid circulation, and of course feebleness, if not disease; and this continued must unfit us for a climate in which, after all, we must at times be exposed to cold several degrees below zero. Besides high and vigorous health, such health as an eminent physician* defined to be "irrepressible enjoyment,"

* The late Dr. Todd, of Hartford, Conn., the founder of the Insane Retreat in that place, and the instructor in the treatment of the insane of Dr. Woodward, so celebrated as the director of the Insane Hospital at Worcester, of Dr. Brigham, of the Insane

can only be hoped for by those who keep a wider range of temperature than can be had by living in rooms highly heated by stoves and furnaces. These send not forth the rosy cheek and the bounding pulse; but the sallow face and the nerveless arm. It was not thus, when we of New England origin were warmly clad with the fleeces of our fathers' sheep, spun by our mothers' hands; and with no lack of ventilation sat around the blazing logs of wood felled in their forests; and which scarcely needed division to fit them for the generous fire-place. Then were men raised who "spread the nostril wide" to the coldest breeze, and whose nerved arm struck the tremendous blow which gained us freedom.

We must change our habits before we shall again be a healthy nation. We must, in winter, breathe within doors an air of more nearly the temperature of that which awaits us without; and depend more on suitable clothing to keep in our vital heat, and on exercise, which hastens the colder blood from the

Asylum at Utica, and of Dr. Rockwell, of the State Lunatic Asylum at Brattleborough, Vt., and of the late Dr. Thomas Lee of the Charlestown Asylum, near Boston. Dr. Todd was a man of whose genius any country or any profession might have been proud.

extremities into the lungs to excite them to quicker action.

With what pleasure do I look upon healthy little boys rolling and tumbling in the snow, with cherry lips and rosy cheeks! I have seen them to-day,and their merry laugh seems now ringing in my ears. No matter how coarse their garb, they are objects of envy, rather than those children whose wealthy, careful parents coop them up at home, in heated houses, until their vital heat is low, their ordinary range of temperature is narrow, and their lungs become unfitted to sustain any other. Then let the parents cover their darlings as they may, they will find, that on slight exposures to cold air they will contract diseases of the lungs or of the circulation; and thus their mistaken tenderness will entail upon their offspring an imbecile life or an early death.

SECTION III.—VENTILATION.—PRESSURE ON THE CHEST.—FEVERS.—DANGERS FROM QUACKERY.

We have already had much good advice on the subjects both of ventilation and of guarding the organs of respiration against undue confinement. But the reason given has been obscure. We are told that the blood must be *aerated*, but why none can

tell. If we are told and believe it, that we must freely breathe good air, and avoid tight-lacing, because the blood must *be warmed and circulated*—that we all know is a good and intelligible reason; and we are a people more inclined to guide ourselves by our own views of the consequences of our conduct, than by the uncomprehended precepts of authority.

If what was said in a former section on the subject of fevers be allowed, it will show us what opposite causes, according to this theory, may produce this class of diseases. There are also other causes of fevers besides those mentioned in the section alluded to, which are connected, more or less, ultimately with the circulation. It is pure, healthy blood, and that alone, which gives to the lungs their proper stimulus. Take suddenly away a quantity of blood and the lungs stop; let them be over-supplied and they are over-stimulated. Let the liver do its office ill and an unhealthy mass may be sent forth to irritate the lungs, and produce bilious fever. Let the skin, as before remarked, close its pores, and the whole body becomes of nearly the same temperature, and there is scarcely any circulation whatever. Again: the skin communicates with the exterior air by its pores, and may imbibe poison from the atmosphere, or from plants; or, being punctured, it may receive the

virus of disease, as the small pox. Health is one—but disease, its name is legion.

Shall we not then be warned against the danger of employing quacks, who treat all diseases alike, whether with cold water, with steam, or cayenne pepper; and of the safety of applying to a physician who shall understand their type, and know how to treat them accordingly? Lately in conversation with a medical gentleman of high eminence, I asked him how long he thought it would take a cold-water quack to kill a patient who had a fever caused by morbid increase of action in the lungs? He replied that he had lately been furnished with an opportunity to know. A patient of his, with such an inflammatory fever, had, under the drenching of the cold-water doctor, died in ten minutes from the time of applying the cold bath. Since writing the above, I learn that a young lady, who, to my knowledge, had symptoms of disease of the lungs, put herself under the care of a cold-water doctor, and soon died. The principle of the expansive theory would lead us to expect, in such cases, a fatal result. And capsicum, the great Thompsonian remedy, whose use is to quicken the powers of life, that they may resist disease, would, where the disease itself is a morbid excess of action in the

vital organs, as surely, though perhaps not as rapidly, produce death.

SECTION IV.—MY OWN EXPERIMENTS.

I MAY be asked for experiments by which to prove my theory. I have made one which I would not advise any person to repeat; for the same result might not again occur. For three years and a half, especially during the winter, I labored from twelve to fourteen hours a day, in study and writing, and when my labors were accomplished, I had better health than I had at their commencement. Yet should any like me, be so situated as to have a certain literary labor to perform in a given time, they might wish to know what light this theory could afford to enable them to endure for a continuance so many hours of daily mental labor without loss of health. In the first place, I selected an ample room with a fireplace, and kept none but an open wood fire; for air, as well as blood, is best circulated when the heat is generated in one place, where the colder particles move towards it to fill the vacuum made by the escape of the warmer. Then I looked out for a supply of good fuel, and periodically applied it to its proper use, knowing that there must be a regular

supply of carbon as well as oxygen, or otherwise there will be neither heat nor circulation. If, after all, my instinctive feeling of coldness warned me that too much heat was going off the surface for that renewed at the vitals, I knew that this monitor, like a physical conscience, must be regarded, and I threw a shawl or cloak around me, as I sat at my writing. Knowing that the rapid course of the blood to the head may be morbidly accelerated by the action of the brain, and so leave the feet without their proper supplies, I was especially careful of the comfort of these humble friends; for if the circulation stops there, where there is the most danger of its stopping, sooner or later a general disorder of the circulation must supervene.

At night, even in the winter, I dropped my window about half an inch beneath my window curtain, for the admittance of fresh air without currents, as I wanted it for my lungs, and not for the surface of my head. In the morning I generally exercised about an hour, in accordance with some house-keeping habits. During the day I took exercise about once in two hours. Letting down the upper sash and facing the current of fresh air, I began moderately, and increased my exercise till it became for a few moments violent, stepping backwards and forwards to keep

my face to the window, and moving my arms in a manner to expand my chest. Then as the quick, deep breathing came on, and the inspirations of air were as refreshing as water from a cool spring in summer, I checked my exercise to give full play to the respiratory organs, and when I had breathed the pure air till I was satisfied, I closed my window, sat down and wrapped my cloak around me to await a gentle respiration, and still for a few moments longer to make breathing my chief employ. The additional garment kept the added temperature which the exercise had given me from going off by evaporation ; and this danger past, I sat down to my writing with fresh blood in my brain and in my hand, and with a warmth far more genial than that of a furnace heat.

After dinner I "slept awhile," and then employed myself in reading, as a lighter mental exercise than writing. After tea I completed the old rhyme by "walking a mile ;" and in the evening I was as vigorous for writing as in the morning, and often wrote five hours before retiring.

On one occasion I found the smoke issuing from crevices of the wood-work about my chimney. I was as much alarmed as I should have been by a cough or any symptoms of lesion of the lungs ; for I

knew that fire was not to be trifled with, and there was great danger when anything went wrong about the place for containing it. Not knowing precisely what was the difficulty—never having served an apprenticeship, and being without experience in such matters, I sent forthwith for a regular mason, who took down a part of the chimney and then rebuilt it, so that the whole affair having thus been taken in season, was once more restored to good order.

Whoever will take the pains to look back to meteorological tables, will find that the last days of the year 1835 were intensely cold; the thermometer, in the northern sections of the Union, ranging from ten degrees below zero to the freezing point of mercury. As this extreme cold was commencing, I left Troy one night at twelve o'clock, and took a seat in a stage for Bennington, Vermont. There was no sleighing at the time, and the stage was shattered by a summer's wear, and scarcely fit for use. For a great part of the ride of thirty miles I was the only passenger, and the thermometer as I afterward learned, was sinking from ten to twenty-five degrees below zero during the time which elapsed from my leaving Troy to that of my arrival at Bennington, a period of about five hours. Though warmly clad I felt myself in danger of perishing. I knew not how cold it

was in reality, or I might have lost heart and hope; in which case I should most certainly have frozen to death. I thought of my theory, and felt tempted to try the experiment of using my voluntary muscles of respiration for the purpose of getting more animal heat. I do not now speak from mere recollection, for I have a written description of this experiment, made soon after the time. I entered upon it with a feeling that it was a fearful thing to tamper with breathing. But my necessity was urgent, and I breathed violently for some minutes that dense air. It felt for the moment cold to my lungs, but soon came heat, and with it distressing pain, as if the whole surface of the throat and lungs were blistered. I thought I had taken my death, and that foolishly, and perhaps wickedly. However, these symptoms went by, but left me afraid of such experiments, as no doubt there is cause. Yet I have often thought it possible that the heat thus gained, with the mental agitation attendant upon it, saved my life in that extremity. Could I have contrived some violent exercise which would have carried the cold blood to the lungs and excited them by this natural means, then when they worked rapidly they would have had the colder blood in larger quantities to work upon, and would have received no injury to themselves. Yet

the experiment was one which confirmed in my mind the belief that animal heat and circulation depend on respiration.

One more experiment I will give, by which my theory, through the blessing of God, suggested to me the means of saving in a sudden emergency the life of a fellow being. Passing by a laundry I saw, by the sudden opening of a door, a woman lying on the floor gasping as if in the agonies of death; she was already speechless. I soon perceived the cause; there was a large crack in the stove burning charcoal, by which she had been ironing. I knew nothing—recollected nothing of the treatment of such cases; but my theory was in my mind. She had women around her who shut the doors and windows, because she was shuddering with cold. I reflected that she had breathed a heavy and poisonous gas, a part of which remained in her lungs; and animal heat had sunk from want of oxygen. I caused the doors and windows to be opened, and called for a fan. Believing that respiration is best accomplished, and most readily produces circulation when the trunk is upright, I raised her up and then fanned her; but I caused hot flannels to be wrapped around her, and her limbs rubbed. To excite the nerves of respiration, I attempted to give her brandy with

warm water, and with extreme difficulty succeeded in getting down a few drops. She revived—took more, and was soon past the dangerous crisis. Whether this treatment was or was not according to the books, I know not to this day; but this I know, it was according to the theory of expansive power by respiration, and it was successful.

SECTION V.—EXPERIMENT RECOMMENDED TO A YOUNG LADY.

Would you, my fair young friend, my truly gentle reader, make experiments for yourself? You need kill no kitten or puppy;* for the proper action of the vital powers must be learned from the phenomena

* I would not be understood as uttering a sweeping anathema against *all* experiments, made for the benefit of the human race, at the expense of the suffering of brutes. But they are creatures of God, and should not be *idly* tortured or destroyed. To wound or kill them to find out whether respiration and circulation are inseparably connected, seems to me an idle torture; since the universal experience of animal nature goes to show that God has conjoined them. The experiments of Dr. Hope seem of a different character, as there appears no way to understand and alleviate human suffering in regard to diseases of the heart, but the one which he pursued.

which they present in the living healthful subject. If Copernicus could have taken down the stars and looked at them, and had he even chemically analyzed their atoms, all this would never have revealed to him the secret of their motions. To account for these, many hypotheses had been made, and each in turn believed in, till stubborn facts which would not bend to agree, at length overturned them all. Then Copernicus made another supposition to which all the essential facts agreed, and which explained all the great phenomena. Still, those who had not faith enough to take in idea the "heliocentric position," could see no beauty or harmony in the system. Their minds, like their feet, clave to the earth; and hence bodies which the system declared to be moving from west to east, they saw only as going from east to west.

Experiment on your own frame; but in a manner to gain health while you acquire knowledge. Try, then, unless domestic duties give you sufficient exercise at home, the experiment of walking briskly up a hill in a cool morning, either after breakfast or before, as best suits your constitution. As you begin to ascend, the muscles which move the foot which is bearing your weight, will distend with force and press the blood from the contiguous veins. It cannot

return to the foot, for valves close against it in that direction, while others open in the course which leads to the heart and lungs. When the rising foot allows the muscles to contract, a vacuum is left in the veins which must be filled from below. This happening successively in each limb, the blood will rise to the right side of the heart with unwonted rapidity, and stimulate that organ to quicken its beat, and the pulmonary artery (vein I think it should be called, since it carries venous blood), will carry an unusual quantity of blood to the lungs. Now, here comes the proof of the expansive theory. If the lungs have as little to do to move the circulation as the veins and arteries, they may in this case remain as passive as those conductors are while the heart sends this tide of blood through their lobes; and this inactivity of the lungs, though it might prove injurious by ill prepared blood going into the circulation, would cause no congestion—no suffocation by filling the lungs with blood. But you know by your own sensations, and the books will tell you, that if you do not breathe faster and deeper as this larger quantity of blood enters the lungs, they would become filled, and you would die of suffocation.* But be not

* Since the above was written, the same argument to prove the

alarmed; you will breathe deep, and fast, and free. Nature by an irresistible instinct gently compels you to do so. The renewed current of life will flow rapidly into the heart's left ventricle, and thence to the aorta; and do you not know by your sensations that this process has evolved caloric? Now rest on the brow of the hill and view the landscape beneath. You still breathe deep, and instinctively turn your face to the breeze, and did you not find like Shakspeare's Cleopatra, that "it did glow the cheek which it did cool?" But now you feel uneasy sensations as your temperature rises to fever heat. Fear not. He, who so careth for you that not a fibre of those silken tresses shall fall unnoticed by him, has

force generated by expansion, was suggested by a Reverend gentleman to whom the theory was explained. The case which he stated was of death by hanging. When the breath was stopped, he said the pulse went down and wholly ceased in about five minutes; and why, if the heart's beat carried on the circulation, why should it stop so soon? It might be said because the blood at the lungs was not aerated; but though that is a reason good as far as health is concerned, it is good for nothing respecting the *motion* of the blood; and why, if the heart was the motive power it did not continue the circulation longer he could never understand; but according to your theory, he remarked it must be so; for when the lungs cease to send blood to the heart its circulation must stop for want of stimulus

provided for you in this further emergency. He will cause the kindly dew of perspiration to envelope you, and the same breeze which supplies the caloric for your lungs will load itself with this dew, now expanded to vapor, and thus carry off your oppressive heat.

Possibly you have provided yourself with a little instrument invented in ancient times, for an assistant to the breezes. It will lessen the labor of breathing, and widen the range of temperature by cooling the surface, while it supplies oxygen to the lungs. This little instrument is called a *fan*. Think not that the rosy glow which is now brightening on your cheeks has no other use than to add to the beauty of their rounded form, or that there is no significancy in their being placed contiguous to the lips and nostrils. The circulation brings to them a greater quantity of blood than to any other part where it visits the surface; and you may never wholly exclude them from the air; for you must always breathe, and the atmospheric current which is passing with your inspirations to the lungs, must make a cooling sweep over your cheeks, and thus furnish some aid to the motive powers.

But the heat passes off, and you no longer feel the necessity of rapid breathing. The range of your

temperature, however, remains extended, and you feel the heart-gladness of unobstructed youthful circulation. Grace is in your elastic step, and beauty in your brightened eye, and the fresh-blown rose of your cheek now no longer mingles its hue with the lily's to the confusion of both.

SECTION VI.—CARE OF HEALTH, ADDRESSED ESPECIALLY TO YOUNG LADIES.

When I am speaking to young girls (the Lord bless and keep them), I am in my proper element. Why should it be otherwise? I have had five thousand under my charge, and spent thirty years of my life devoted to their service; and the general reader will excuse me if I add some further advice to them, which the light of this theory will show to be good. If it is so, others may have its benefit as well as they, but it is most natural to me to address myself to them.

Would you, my dear young ladies, do the will of God on earth by being useful to your fellow-beings? Take care of health. Would you enjoy life? Take care of health; for without it, existence is, for every purpose of enjoyment, worse than a blank. No matter how much wealth or how many luxuries you

can command, there is no enjoyment without health. To an aching head what is a downy pillow with silken curtains floating above? What is the cushioned landau and the gardened landscape to her whose disordered lungs can no longer receive the inspirations of an ordinary atmosphere? And what are books, music, and paintings to her whose nervous sufferings give disease to her senses, and agony to her frame?

Would you smooth for your tender parents the pillow of declining life? Take care of health. And does the "prophetic pencil" sometimes trace the form of one whose name perhaps is now unknown, who shall hereafter devote to you a manly and generous heart, and marriage sanction the bond? Would you be a blessing to such a one? then now take care of your health: or if you hesitate, let imagination go still further. Fancy yourself feeble as with untimely age, clad in vestments of sorrow, and leaving a childless home to walk forth with him to the church-yard, there to weep over your buried offspring.

Study then to know your frame that you may, before it is too late, pursue such a course as will secure to you a sound and vigorous constitution. Study what I have written in this book among other means, and here learn that to be careful of your health is to

accustom yourself to bear, without inconvenience, the full range of temperature to which you must sometimes be exposed by the climate you live in. When you go forth, erect your form, expand your chest, and let your organs of respiration and your cheek meet the full current of air which your onward motion produces, and sets against you. If you have heretofore believed that this was a dangerous exposure, and have covered your face from the wintry air as you went abroad, on foot or otherwise, now learn that this is a mistake. But if you have already practised it till your lungs, like a dyspeptic stomach, cannot digest their wholesome aliment, then you must not change your habits at once, but by degrees. Pass no day without invigorating the circulation by exercise more or less energetic. Be careful to take regularly the simple diet which Nature requires, but shun all beverages and condiments which unduly excite the nerves and disorder the stomach, for the nerves are the media through which the lungs derive their vital power, and the stomach, that through which the blood itself is formed; and to no purpose is the channel for circulation and the motive power, if there be no healthy blood to be circulated.

Have the good sense to disregard fashion when it would lead you to imprudence in dress. You dress

for beauty as well as for health. That is right, for God himself has not disregarded beauty in his external creation, and beauty is the child of nature and simplicity, not of ornament, extravagance and affectation. But study nature's fine models more than fashion plates, and you will gain in beauty as well as in health. The attenuated waist, and the Chinese foot are not divinely made, but fashion-formed, and are nothing better than superinduced deformities. As to pressure on the lungs, enough has been said for you to remember its danger. But the pressure on the stomach is also deleterious, and that on the liver may be both fatal to health and destructive of beauty. If the vital motions of the liver are obstructed, the yellow bile pervades and disorders the general system, and ruins the complexion. Be careful to clothe your feet properly, and press them not too closely. A free circulation cannot go on if obstructed here, and here is the greatest danger of obstruction. Be not over anxious then to have a tiny foot; for undue pressure on the feet and carelessness in keeping up warmth at the feet by proper covering, have perhaps destroyed as many female lives as unnatural pressure on the lungs. Unnatural pressure on the lungs, the stomach and the liver, annihilates real beauty of form and complexion, and pressure on the

feet, its finest accompaniment, grace and dignity of motion. The French women are allowed to be the most graceful in the world, and their feet are well grown. Taglioni, the very queen of grace, had large, but well shaped feet. But who thought of this as in the dance she seemed to float on air? Then the eye could detect no jar when in descending she touched the floor, nor any appearance of effort when she rose, but the wavy line of grace remained unbroken. Such perfection of movement a very small foot could not have allowed.

The important office of the skin we have already discussed, and you will be better able now to comprehend why "cleanliness is next to godliness." Finally, my dear young friends, guard by proper clothing the region of the lungs. I verily believe that a quarter of a yard of flannel applied in due time to the chest, would have saved many a death by consumption. In our cold climate, that so many should have lived to so expose the neck, breast and shoulders, is only to be accounted for on the supposition of the upward tendency of a heating agent. But many, by tempting nature too far in this particular, have gone to untimely graves. You have seen how necessary to circulation and to life, is the heat at the lungs. Guard it then, with a care exceeded

by no other, except that which should be paid to keeping in vigorous flow the fountain-spring of spiritual life. As coldness in this respect speaks of spiritual death, so does the chill which reaches the vitals, warn of the death of the body.

CONCLUSION.

THE THEORY OF MOTIVE POWERS BY EXPANSION NOT DISPROVED BY THE EVOLUTION OF CALORIC IN THE DIGESTIVE SYSTEM AND SOLID PARTS OF THE BODY.

In maintaining that the blood receives caloric at the lungs, we by no means deny that there is caloric evolved in other parts of the system by chemical changes. There is no doubt that heat is evolved by the vital and chemical processes of composition and decomposition, by which all the solid parts of the body are daily receiving new particles from the arterial blood, and sending off the used and waste ones in the venous current; probably to be separated from it in the kidneys and liver. In the digestive organs, also, caloric is evolved. The region of the stomach often remains warm for some time after respiration and circulation have ceased and death has supervened. But suppose it could be proved (which it

cannot) that the solid parts of the body and the digestive system were thus kept up to a temperature of 78°, still this would not subvert our theory. The equal temperature of the pipes which convey water through a building would not hinder the circulation of the water by means of heat applied to a reservoir rightly located. The pipes which convey the mass of blood would not, though thus warmed, warm the circulating fluid as we find it in the animal system. The blood must have a source of heat peculiar to itself. No one will deny that it has. No one acquainted with the subject will deny that respiration furnishes this source. But *where* is the heat developed which warms the blood? Surely, at the lungs, where oxygen meets carbon, and where the flame color rises, and where one-fourth or fifth of all the blood is collected, and in a receiver perfectly fitted for the purpose.

If the change of the blood's color in the lungs is owing to the combustion of carbon there, then it proves that such a combustion occurs in the lungs, and there only; because it is only there that this change of color occurs. But if the change is caused, as some late chemists suppose, by the chemical union of minute particles of coloring matter, which must have existed together in the blood in the veins, then

the superior heat of the lungs is the only cause which can be assigned why the particles do not unite until they reach the lungs, for heat is the only assignable agent for quickening chemical action. We care not which supposition is made. Either supports our theory, and either disproves the strange supposition that the oxygen received at the lungs does not then chemically combine with the carbon of the venous blood, but passes into it by absorption to burn all along the arteries and veins, for if it did, wherever the combustion occurred, whether in the lungs, the arteries, or veins, there this change of color must be going on. But no change from red to redder occurs in the arteries, and none from darker to less dark, occurs in the veins. In the lungs alone is this change from dark to flame color, and in the lungs alone is the source of the blood's heat.

It appears to me as absurd to deny this and to affirm that the blood is heated indiscriminately throughout the sanguineous system, as it would be to deny that the source of nervous activity is in the brain, and to affirm that it exists indiscriminately throughout the whole nervous system. Let any part of the nervous system be divided from the brain, and the brain remains the same, and affects as before every other part, while the arm or leg whose nerves

are so divided is powerless and inactive. This shows that it is not the nerves of the arm or leg which affect the brain, and that there is no source of voluntary motion in them, but that it is the brain which furnishes the nervous energy of the whole system; for let the brain be destroyed, and the whole nervous power of the system is at an end. In the same manner we may prove that the source of animal heat is not equally generated in every part of the body. If an arm or a leg in any way cease to receive heat from the lungs it becomes cold, while the lungs and every other part of the system are warmed as before; but let the lungs be frozen, and animal heat is as much at an end as nervous power is when the brain is paralyzed.*

It is a broad undisputed fact and of the utmost moment to our race, that while life lasts, respiration, animal heat, and circulation will go on together, and when life expires, together they cease. Who, then, can doubt that they are connected as cause and effect? But here we must make the logical distinc-

* The "Conclusion," up to this point was written after the work was in the hands of the publishers, and the author being at a distance from New York, could not have access to the manuscript. This may account for any repetitions which it may contain of other parts of the work.

tion between physical and final causes, for although there is reason to believe, nay, we think we have clearly proved that respiration is the physical cause —the invariable antecedent of animal heat and circulation, yet there is reason to believe that circulation is the *final* cause both of respiration and animal heat; or in other words, that the reason why the Creator has obliged us to breathe, and given us the instinct of animal heat, is for the purpose of impelling us to keep up and guard the circulation. Many of the considerations previously stated have a bearing on this point, and it appears to me that the honor of God, as well as the good of man, is concerned in the argument. He, so wise and good, would not have given us the inconvenience and exposed us to the dangers attendant on respiration, without an adequate object. To keep up the circulation and furnish the last preparation of the aliment is an adequate object, and what other can be assigned? The production of animal heat, in one way or another, is universally ascribed to respiration. Yet that man may feel a comfortable warmth is no more an ultimate end than that he may enjoy the pleasures of eating and drinking. The Creator annexed pleasure to the means by which his wise ends are to be accomplished in the preservation of the individual and the race. We

have already shown the importance of the instinctive sensations of heat and coldness, as to those is assigned the care of guarding against fatal extremes which would destroy the healthful balance and annihilate the expansive force which keeps up the circulation. By this instinctive feeling of the comfort of warmth and the dread of cold the savage seeks his cave, fells the forest tree, and covers himself with the skins of animals. In civilized life the mental love of the beautiful, that first element of taste, does but modify the principle that the balance of animal heat must be preserved, and hence arises the palace and the splendid mansion. Hence the green flax-field and the blooming cotton. The sheep yields her annual fleece, and the silkworm his cocoon. To exchange these commodities from land to land, commerce spreads her sails over the deep, and half the occupation of the human race arises from the necessity imposed upon man by the instincts of animal heat to provide himself shelter, fuel, and clothing. Add to these the necessity of supplying the food, which is the means of internal combustion by which animal heat is every moment renewed, and we have the whole amount of man's physical necessities, and they all centre in producing and keeping up a due circulation of healthy blood. We therefore conclude, that res-

piration and animal heat are those adequate means to keep up the circulation which our Almighty Father has in his wisdom been pleased to employ.

When circulation is our life, it behoves us to consider well its causes, that we may add reason to instinct in its healthful preservation. That the blood travels through the system by its own volition, none believe; but that it is an inert mass which will only move as it is moved. What, then, are the forces which move inert bodies? Are there any which may not be resolved into one of these three, impulse, gravitation, and heat; of which the latter has the greater range in point of degree, being in the expansion of a fluid from warm to warmer, the most gentle of all imaginable forces, while in other states it is the most powerful of any known to man. It is then to one or more of these forces that we must look for the motive powers which produce the circulation. And the human circulation has peculiar difficulties to encounter. Man does not enjoy his noble erect position, without some countervailing disadvantages. The long upright column of his blood spreading at its base, presents no trifling force to be moved. And this force is to be overcome by means so gentle that the mind, the dweller in this house of clay, shall not be disturbed by its opera-

tions. Again: the parts of the body are to be used by the mind as instruments, and ten thousand different motions are to be performed at its bidding. What but Almighty Wisdom could have effected these several objects? And is it not most reasonable to suppose that this wisdom would assign for these purposes not any one of the forces which move matter, but combine them all? Gravitation by itself cannot produce a circulation by any machinery. Impulse alone could not carry on a circulation without existing in such an excessive degree that it must disturb the mind and endanger the body. But heat, the antagonist force of gravitation, by the lessening or increasing of the maximum and minimum difference, can operate more or less forcibly as occasion requires, and at the same time so gently and so quietly, that the mind shall take no cognizance of its operation as a moving force. It can be so placed that by its expansive force it shall lift gravitation when that obstructs the way, and by its transmission leave to it the course, when its presence as a force would become hurtful. Why, then, should we hesitate to conclude that this is the principal force employed, since we know that it exists in the human system? And if it is the principal agent which does actually perform this great work, then if the quantity

afforded be small, so much the more perfect the machine, for so much the less will it be likely either to endanger the body or disturb the mind, and so much the more praise is due to the Mighty Artificer.

APPENDIX.

THE following letter from Dr. Marcy, of Hartford, is deserving of much consideration, not only on account of the known talents and high standing of the writer, but from the fact that the subject of the Motive Powers had particularly occupied his mind during his studies, and in the course of his extensive practice. The paper spoken of as having been read by him, was a manuscript copy of this treatise as contained in the first chapter. Dr. Marcy has recently assured me that he is now fully confirmed in the correctness of my views, having watched phenomena and made experiments in order to test their truth. He has urged me, as others have done, to publish the theory; and he has added the generous assurance that he is not unwilling to be known as its advocate and defender.

Dr. Marcy has seen the expansive theory from its heliocentric position, and thence discerns the simpli-

city of movements, before seemingly complex and anomalous. And when other physiologists and pathologists will give sufficient heed to the subject to inquire what are the results which we are to expect, on the supposition that this theory is true, then they will find it true by the recurrence of those results? "From faith to faith" was the only way, St. Paul tells us, in which the Gospel itself could be revealed.

"*Hartford, June* 1, 1840.

"To Mrs. Emma Willard:—

"My Dear Madam—I have perused, with much pleasure, the paper with which you had the kindness to favor me, and I regret exceedingly that my professional duties will not permit me to devote much more time to this interesting subject than I at present am able to do. It is with great confidence, however, that I can assure you that the theory which you have advanced in regard to the circulation of the blood is one which deserves the attention of all lovers of science.

"As yet I have been able to find no valid objection to your views—but have thought of many things which go to strengthen them. 1st. It is granted by all that when we breathe air into the lungs, a chemical change is effected and the blood which is present acquires an additional amount of *caloric*. We also know equally well that whenever a given quantity of fluid is heated it expands, and requires more space to contain it, and as you truly observe in your communication, it must rush into the passages which are open to receive it.

"When we reflect upon the quantity of air which is constantly entering the lungs, and how many chemical changes take place in a given time, we can easily conceive how much caloric must be developed, and how much motive power must be caused. It is supposed that we breathe, on an average, twenty times a minute (28,800 times in 24 hours). The medium quantity of air which enters the lungs at each inspiration is 325 cubic inches (48 pounds in 24 hours).

"This, then, may be set down as the true quantity of air which Nature intended that we should constantly inspire, in order that the function of inspiration may be properly performed. We will suppose now that some morbid agent acts upon the system. What is the result? The heart (which is possessed of nerves of every description) is increased in its action, and throws more blood into the lungs than usual; consequently, the inspirations must be more frequent and vigorous in order that all the extra fluid may be oxygenated, and the requisite quantity of *caloric generated* to keep up this increased action of the heart and arteries, and thus enable nature to throw off the morbific influence.

"If we make but half the usual number of inspirations for a length of time, there will be a *material diminution in the temperature of the body*, and a *diminished number of pulsations in the heart and arteries.* If an animal be placed in an atmosphere from which a portion of oxygen has been detracted, the heat of the animal will subside, and the circulation become slower and more labored. These facts prove conclusively that the *action* of the circulatory vessels depends upon the *function of respiration;* for we think it can easily be established that there can be no

great increase in the circulation without a corresponding increase of the inspirations. Observe any case of fever where the pulse is rapid, and the breathing will be quick, with occasional very deep inspirations. The *animal heat* will also be proportionally elevated.

"Thus we see that a certain quantity of air must constantly come in contact with the blood in the lungs, in order that the circulation may retain its *equilibrium* and the *temperature* of the system kept at 98° Fahrenheit. If more than the given amount of blood is oxygenated (as when we make forty or fifty inspirations in a minute, or when we breathe pure oxygen gas), a greater amount of *caloric* is acquired; consequently, there must be *expansion*, *increased motion*, and an *elevation of temperature*.

"In cases of suspended animation, *respiration* must be established before the blood can regain its wonted motion, and the body its natural heat. How important then, in these cases, that *artificial respiration* be at once instituted! I have myself saved more than one life by simply keeping up artificial respiration until sufficient vitality returned to enable the system to act properly.

'Thus have I penned you a few 'off-hand ideas' which have occurred to me in regard to the chemical theory of the Circulation. I trust that I shall be able, ere long, to make some accurate experiments upon the subject. Should any new ideas occur to you respecting the subject, I shall feel honored in receiving a communication from you. Yours, truly,

"E. E. Marcy."

The effect of the caloric of radiation upon the venous circulation, was first suggested to me by Mr.

S. A. F., a highly distinguished lawyer of New York. This gentleman, in 1841, read the theory as contained in the first chapter, and pronounced it true. Yet, he said that he doubted whether there was as much difference in the temperature of the blood, in the two sides of the heart, as I seemed to suppose; for the returning blood would be warmed before it reached the heart by the heat of the internal parts of the body; but said he, "that makes no difference in the principle of your theory."

Subsequent reflection convinced me of the truth and the importance of this suggestion, which I now adopt as a constituent part of the theory. Other distinguished lawyers have given their full assent to the principles herein advocated. Among mathematicians I could name distinguished persons as its supporters; and Henry Barnard, Esq., after reading it with attention, said he could see no valid objection against it.

THE USE OF THE LUNGS ON THE FORMER THEORY OF THE MOTIVE POWERS NOT ACCOUNTED FOR.

"It does not, I think, appear, that we are acquainted with the action of the air upon the blood, or in what manner that action is communicated by the lungs; yet we find that a very short sus-

pension of their office destroys the life of the animal. In this case, therefore, we may be said to know the use, nay, we experience the necessity of the organ, though we be ignorant of the operation."—*From Paley's Theology.*

LUNGS ARE AFFECTED IN FEVERS.

"There are very few, if indeed any, of the numerous maladies which are usually denominated infectious, that are not caused through the medium of the lungs. Probably marsh miasmata and noxious animal exhalations, act directly on the organic nerves of the lungs, and on the blood itself through the medium of obstruction. We have reason moreover to infer, that the more material causes of disease are absorbed from the surface of the lungs, when inhaled into them from the atmosphere, in the moisture of which they are dissolved or otherwise combined; and also that the foreign gases which sometimes mix with the air, act in some measure through the same channel."

"Through this channel (i. e. the lungs) a number of fevers, especially those which are characterized by great depression of the powers of life, or which rapidly pass into this state—various chronic affections of the lungs themselves, which are unattended by acute inflammation—diseases which threaten life by interrupting the respiratory functions, and various maladies where it becomes important to act in a direct and decided manner on the blood and the circulating organs generally, may be successfully combated."—*Copland's Dictionary of Practical Medicine.*

HEAT EVOLVED BY RESPIRATION, AS ESTIMATED BY LIEBIG. (See "Animal Chemistry.")

As the theory herein advocated is often questioned concerning the quantity of heat in the animal frame, whether there is enough for such an expansive power as we advocate, we therefore subjoin the following calculations from Liebig's "Animal Chemistry:"

"According to the experiments of Despritz, one oz. of carbon evolves, during its combustion, as much heat as would raise the temperature of 105 oz. of water at 32° to 167°, that is by 135 degrees; in all, therefore, 105 times 135=14207 degrees of heat. Consequently, the 13·9 oz. of carbon which are daily converted into carbonic acid in the body of every adult, evolve 13·9x14207° =197477·3 degrees of heat. This amount of heat is sufficient to raise the temperature of 1 oz. of water by that number of degrees, or from 32° to 197509·3°; or to cause 136·8 lbs of water at 32° to boil; or to heat 370 lbs. of water to 98·3° (the temperature of the human body); or to convert into vapor 24 lbs. of water at 98·3°.

"If we now assume that the quantity of water vaporized through the skin and lungs in 24 hours amounts to 48 oz. (3 lbs.), then there will remain, after deducting the necessary amount of heat, 146380·4 degrees of heat, which are dissipated by radiation, by heating the expired air, and in the excrementitious matters.

"In this calculation, no account has been taken of the heat

evolved by the hydrogen of the food, during its conversion into water by oxidation within the body. But if we consider that the specific heat of the bones, of fat, and of the organs generally, is far less than that of water, and that consequently they require, in order to be heated to 98·3°, much less heat than an equal weight of water, no doubt can be entertained, that when all the concomitant circumstances are included in the calculation, the heat evolved in the process of combustion, to which the food is subjected in the body, is amply sufficient to explain the constant temperature of the body, as well as the evaporation from the skin and lungs.

"All experiments hitherto made on the quantity of oxygen which an animal consumes in a given time, and also the conclusions deduced from them as to the origin of animal heat, are destitute of practical value in regard to this question, since we have seen that the quantity of oxygen consumed varies according to the temperature and density of the air, according to the degree of motion, labor, or exercise, to the amount and quality of the food, to the comparative warmth of clothing, also according to the time within which the food is taken. Prisoners in the Bridewell at Marienschloss (a prison where labor is enforced) do not consume more than 10·2 oz. of carbon daily; those in the House of Arrest at Giessen, who are deprived of all exercise, consume only 8·5 oz: (6) and in a family well known to me, consisting of nine individuals, five adults, and four children of different ages, the average daily consumption of carbon for each, is not more than 9·5 oz. We may safely assume, as an approximation, that the quantities of oxygen consumed in these different cases are in the ratio of these numbers; but where the food contains meat, fat, and wine, the proportions are

altered by reason of the hydrogen in these kinds of food which is oxidized, and which, in being converted into water, evolves much more heat for equal weights.

"The attempts to ascertain the amount of heat evolved in an animal for a given consumption of oxygen have been equally unsatisfactory.

"These experiments and the conclusions deduced from them, in short, are incapable of furnishing the smallest support to the opinion that there exists in the animal body any other unknown source of heat, besides the mutual chemical action between the elements of the food and the oxygen of the air. The existence of the latter cannot be doubted or denied, and it is amply sufficient to explain all the phenomena."

QUOTATIONS SHOWING THE IMPORTANCE OF THE SUBJECT OF PHYSIOLOGY.

From the Educator—Prize Essay.

"The regular action of the muscles promotes and preserves the uniform circulation of the blood, which is the prime condition of health."—*Lalor.*

"There are two deeply important branches of study. 1st. The structure of the body. Such knowledge would prevent injurious practices, as want of cleanliness, deficient ventilation, excessive or insufficient exercise, over-action of diseased organs. People may be told for ever that they must have a regular supply of fresh air; they assent in words, but forget it, because it does not get into their thoughts; a single exposition of the use of the blood,

and of the part performed by the lungs, would stamp the idea deeply.

" Mothers, in fact, make society what it is, for the physical and moral tendencies are generally communicated or excited before the child passes from the sphere of the mother's influence. Thus is a two-fold necessity for making this study a part of female education, to enable women, as individuals, to protect their own health, and co-operate in their own physical education, and to enable them, as mothers, to do all that enlightened reflectiveness can for the happiness of the beings entrusted to them.

" In addition to these obvious utilities, it deserves a front place in education as matter of science. No object in external nature presents combinations so varied and beautiful, or instances of adjustment so likely to fill a young mind with wonder and veneration as the exquisite mechanism of life."

THE END.

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